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Of Interest to Managers

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In the current state of severe drought in California and the San Francisco Bay-Delta, there is increasing demand for new field studies that inform management of critical water operations, document the state of the estuarine ecology, and synthesize existing data to understand ecosystem function. The Summer 2014 issue of the IEP Newsletter highlights each of these aspects of current science in the Bay-Delta, with one highlight piece, two status and trend pieces, and two full articles addressing recent questions and concerns of food web productivity and Delta Smelt vulnerability to entrainment.

Peggy Lehman and **Tiffany Brown** (DWR) offer a brief highlight article describing the methods for the multi-decadal IEP Environmental Monitoring Program (EMP) dataset for phytoplankton, with examples as to how the data has been used to identify temporal changes in the phytoplankton community of the Delta.

Leo Polanksy (USFWS) and co-authors provide an analysis of the spring 2014 "early warning" sampling for Delta Smelt at Jersey Point. This article describes a new sampling effort intended to determine whether adult Delta Smelt were moving toward the South Delta pumps. This monitoring was meant to be responsive to the extremely low 2013 FMWT abundance index for Delta Smelt and the potential for a southerly Delta Smelt distribution should turbidity become elevated in the South Delta region. Near daily sampling at Jersey Point for almost two months revealed elevated Delta Smelt catch after rain events and demonstrated the level of effort necessary to reliably detect Delta Smelt when they are present at low densities.

In a substantial synthesis effort, **Jim Cloern** (USGS) and co-authors used a suite of analyses to address a major question currently plaguing nutrient and food-web scientists of the Delta: is the scarcity of beneficial phytoplankton blooms in Suisun Bay primarily the result of drastic changes in nutrient ratios due to discharge from the Sacramento Regional Wastewater Treatment Plant (SRWTP) or is low productivity more likely an outcome of multiple, cumulative anthropogenic disturbances? Using the IEP Environmental Monitoring Program (EMP) data from 1975-2009 as well as USGS data, Cloern and co-authors present results that fail to support the nutrient hypothesis. In fact, the authors suggest that attributing low productivity in the Bay-Delta singularly to changes in nutrient forms and ratios may lead to a false hope that more stringent wastewater treatment standards for the SRWTP will lead to a restored food web and enhanced fisheries.

The two status and trend pieces highlight IEP work on benthic communities in the Bay-Delta and fisheries and lower trophic communities in the Yolo Bypass. **Betsy Wells** (DWR) provides the 2013 update from the IEP EMP benthic monitoring program, with a series of data summaries that compare 2013 with 2012, both hydrologically dry years. Indicative of dry conditions that bring an increasingly upstream salinity field, Wells highlights that both species of the major invasive bivalves in the Bay-Delta, *Potamocorbula amurensis* and *Corbicula fluminea*, were present in the confluence region during 2013, but that densities of *P. amurensis* (generally the more salinity-tolerant species) peaked sharply in October. Furthermore, some routine sampling locations were occasionally inaccessible in 2013 due to overgrowth of water hyacinth, an invasive floating aquatic macrophyte.

Finally, **Naoaki Ikemiyagi** (DWR) and co-authors provide an update of sampling activities in Yolo Bypass conducted by DWR's fisheries and invertebrate monitoring program for water year 2013. Of particular note in this update is that chlorophyll-*a* concentrations in the Toe Drain exceeded established thresholds (> 10µg/L) for enhanced phytoplankton growth multiple times, a rare but necessary event for phytoplankton growth that is a foundation for the pelagic food web. The 2013 peaks in chlorophyll-*a* were not followed by beneficial phytoplankton blooms downstream (in Rio Vista) as they were in 2011 and 2012. However, the Yolo Bypass monitoring work has spurred a collaborative research effort to understand the mechanisms behind these blooms and investigate management options to induce them in the future. In the fisheries realm of the Yolo Bypass work, Ikemiyagi and co-authors note that despite dry conditions, the monitoring program caught record numbers of Delta Smelt. The 2013 record catch follows closely on the heels of the previous record from 2012, which was also dry.

Did you know that quarterly highlights about current IEP science can be found on the IEP webpage along with a new calendar that displays IEP Project Work Team and other IEP-related public meetings? To view these features see the links below:

http://www.water.ca.gov/iep/activities/calendar.cfm
http://www.water.ca.gov/iep/highlights/index.cfm

The IEP Newsletter is a quarterly publication that provides IEP program and science highlights as well as in-depth articles on important scientific topics for resource managers, scientists, and the public. The spring issue of the IEP Newsletter provides an annual overview of important results from all IEP monitoring programs and associated studies. Articles in the IEP newsletter are intended for rapid communication and do not undergo external peer review; all primary research results should be interpreted with caution.

If you would like to be notified about new issues of the quarterly IEP newsletter, please send an e-mail to Shaun Philippart (DWR), shaun.philippart@water.ca.gov, with the following information:

- Name
- Agency
- E-mail address

Article Submission Deadlines for Calendar Year 2014

Issue	*Article Submission Deadline*
Issue 1 (Winter)	January 15, 2015
Issue 2 (Spring)	April 15, 2015
Issue 3 (Summer)	July 15, 2015
Issue 4 (Fall)	October 15, 2015

Submit articles to Shaun Philippart.

Highlight Article

Environmental Monitoring Phytoplankton Program

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The Department of Water Resources (DWR) and the US Bureau of Reclamation (USBR) are required by Water Right Decision 1641 (D-1641) to monitor change in phytoplankton community composition in order to operate the State Water Project (SWP) and Central Valley Project (CVP). This monitoring program is conducted by DWR's Environmental Monitoring Program (EMP). Long-term trends in phytoplankton community composition and biomass are monitored at selected sites in the upper San Francisco Estuary (Estuary). The sampling sites range from San Pablo Bay east to the mouths of the Sacramento, Mokelumne, and San Joaquin rivers. These sites represent a variety of aquatic habitats, from narrow, freshwater channels in the Delta to broad, estuarine bays.

Historically, phytoplankton samples were collected once or twice per month at 11 to 25 stations. The monitoring program currently consists of 15 stations sampled at monthly intervals. Two of these stations are "floating" and sampling occurs where the bottom specific conductance is 2,000 µS/cm and 6,000 µS/cm, +/-10%. The mixing of river water with sea water creates a wide range of water quality conditions in the sampling region. For example, specific conductance ranges from freshwater in the central Delta to brackish water (30,000 µS/cm) in the shallow bays of northern San Francisco Bay. A suite of water quality variables are monitored at all phytoplankton stations.

Phytoplankton samples are collected with a submersible pump from a water depth of one meter (approximately three feet) below the water surface. Samples are stored in 50-milliliter amber glass bottles. One milliliter of Lugol's solution is added to each sample as a stain and preservative. All samples are kept at room temperature and away from direct sunlight until analyzed.

Prior to 2008, phytoplankton identification and enumeration were performed at DWR's Bryte Laboratory according to the Utermöhl microscopic method (Utermöhl 1958) and modified Standard Methods (APHA et al. 1998). An aliquot of the phytoplankton sample was placed into a settling chamber and allowed to settle onto an inverted microscope counting slide for a minimum of 15 hours. The sample volume, was adjusted according to the algal population density and turbidity of the sample and ranged from 10 ml to 100 ml. Phytoplankton were enumerated with a Whipple ocular micrometer grid for each settled aliquot. Either 20 random fields were counted, or a variable number of fields were counted, until over 100 units of the dominant taxon was reached, whichever came first (G. Weber pers. comm.). Phytoplankton samples were enumerated using a Wilde M-40 inverted microscope; magnification ranged from 280x to 750X (Lehman 1996). Beginning in 2008, the enumeration protocol was modified to more closely reflect the methods outlined in APHA et al. (1998), and has been completed by consulting firms. A minimum of 400 algal units are counted, with at least 100 of those units being from the dominant taxon (genus or species).

The phytoplankton monitoring data have been successfully used to identify spatial and temporal patterns in the phytoplankton community at the class or genus level, and the associated environmental conditions, using non-parametric statistical techniques. Hierarchal cluster analysis of the relative abundance of phytoplankton genera, principal coordinates ordination, and regression analysis identified successional patterns in phytoplankton community composition among different regions of the Delta by season, water year-type, and with a suite of environmental conditions between 1975 and 1982 (Lehman and Smith 1991). The relative abundance or carbon of phytoplankton taxa were also successfully used to identify long-term patterns in phytoplankton community composition and biomass between 1970 and 2007, as well as their correlations with water year type, water quality conditions and zooplankton carbon (Lehman 1996, 2000, 2004, Brown 2009). With application of appropriate statistical techniques, a focus on higher level taxa and basic questions that address trend and relative change, the phytoplankton database can be used to identify patterns in the Delta phytoplankton community over time.

More information on the EMP Monitoring Program can be obtained at www.water.ca.gov/iep/activities/emp.cfm.

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Contributed Papers

Delta Smelt Movement During an Extreme Drought: Intensive Kodiak Trawling at Jersey Point

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Introduction

Delta Smelt (*Hypomesus transpacificus*) is a federally threatened fish species whose habitat includes the low salinity and freshwater zones of the San Francisco Estuary (Bennett 2005). Delta Smelt are associated with shallow-water habitats such as shoals, channel edges, tule edges, and embayments that are about 2-4 m deep (Moyle et al. 1992; Aasen 1999; Hobbs et al. 2006; Murphy and Hamilton 2013; Sommer and Mejia 2013). Delta Smelt likely use these areas because of their tendency toward elevated turbidity and hydrodynamic conditions that help the fish find prey with a minimum of energy expenditure and exposure to predators (Bennett et al. 2002; Hobbs et al. 2006). Important regions containing Delta Smelt habitat include Montezuma Slough, Grizzly and Honker bays, Sherman Lake, Decker Island, and Liberty Island (Moyle et al. 1992; Aasen 1999; Hobbs et al. 2006; Feyrer et al. 2007; Sommer and Mejia 2013).

Generalities about where Delta Smelt are likely to be found are less useful once the first winter rains bring a "first flush" of turbid waters through the Delta, a process thought to coax maturing fish into moving toward spawning habitats (Wang 2007; Grimaldo et al. 2009; Sommer et al. 2011). The redistribution of Delta Smelt has been called "migration" by some authors (Sommer et al. 2011; Rose et al. 2013) and "marshward dispersal" by others (Murphy and Hamilton 2013); henceforth we will refer to this phenomenon as "migration", as we are particularly focused on redistribution of Delta Smelt resulting in movement into the southern half of the Delta, a marginal habitat for Delta Smelt that is only seasonally available for this fish species (Hobbs et al. 2007). Although dispersal into the south Delta was historically a prominent life-history strategy for Delta Smelt (Erkkila et al. 1951; Radke 1966), it may result in an elevated risk of mortality related to entrainment caused by the State Water Project (SWP) and Central Valley Project (CVP) water diversions, which are in the south Delta (Moyle et al. 1992; Kimmerer 2008; Grimaldo et al. 2009).

During the winter months, there is concern that Delta Smelt migration following rainstorms and in combination with changes to Delta hydraulics caused by south Delta export pumping have the potential to result in unacceptably high levels of entrainment. There were two factors of special interest in the winter of 2014: (1) Delta Smelt distribution is believed to at least partly track Delta outflow, with lower outflow years being associated with more easterly and southerly spawning activity (Bennett 2005; Wang 2007), and Delta outflow in the winter of 2013-2014 was very low due to drought conditions; and (2) Delta Smelt relative abundance was low, with the 2013 Fall Midwater Trawl (FMWT) index at the second lowest on record, heightening a concern that the Delta Smelt cohort was particularly vulnerable. Because of these factors and the extreme drought conditions prevailing in early 2014, the Service and others were especially interested in enhancing the array of information available to determine whether and when migratory or other movement of smelt toward the south Delta might be occurring.

The relationship between entrainment and salvage is likely a complex one in both space and time (Castillo et al. 2012). Observation of salvage at the export facilities provides evidence that fish have been entrained, but because salvage merely samples entrained fish, the number of fish entrained – that is, drawn into the export facilities in the south Delta or subject to mortality due to causes associated with being transported into the south and south-central Delta – is likely much greater than salvage. Nevertheless, knowledge about increased densities that are plausibly within the zone of entrainment can potentially inform management of water operations to maximize exports while limiting entrainment mortality of Delta Smelt.

Two surveys are routinely conducted which are most useful for providing information about Delta Smelt spawning activity and subsequent entrainment: the Spring Kodiak Trawl Survey (SKTS) and the 20 mm Survey (20S). The SKTS was designed to determine adult Delta Smelt distribution with a focus on identifying general spawning locations (Souza 2002). The 20S was designed to serve as an 'early warning' survey to provide resource managers with an indication of when juvenile entrainment might be high (e.g., Nobriga et al. 2000). By backcasting, it also provides evidence of where spawning likely occurred. Sampling by these surveys is done at monthly (SKTS) and bimonthly (20S) intervals, an inter-sampling interval potentially too long for detecting abrupt changes in Delta Smelt densities given the weekly or even daily time scales at which abrupt changes in flow and turbidity thought to trigger Delta Smelt migration into the south Delta occur (Feyrer et al. 2013).

During January 2014 sampling, the SKTS had not collected any Delta Smelt in the south Delta (http://www.dfg.ca.gov/Delta/data/SKT/DisplayMaps.asp). Out of concern that the monthly sampling intervals of the SKTS would miss detection of migration by adult Delta Smelt from rearing grounds around the confluence of the Sacramento and San Joaquin Rivers towards the south Delta, the Service rapidly designed and deployed a special study carried out at Jersey Point (SKTS station 809). The study was designed around a very simple conceptual model in which smelt densities are relatively low prior to a migration event, increase during migration towards the south Delta, and decline again subsequent to migration (Figure 1). The special study employed intensive, near daily sampling for approximately 1.5 months, offering a unique opportunity to assess factors determining changes in Delta Smelt catch densities and the sampling effort required to detect them. The objectives of this analysis of the resulting data are to provide (i) a better understanding of what environmental conditions might precede or cause increases in Delta Smelt densities at this location, (ii) identify whether and when increases in Delta Smelt densities occurred, and (iii) to better quantify how much sampling is needed to reliably detect Delta Smelt as a function of Delta Smelt density. Our discussion includes remarks on the value of such studies to provide an "early warning" of an increased probability of entrainment related mortality due to SWP and CVP operations.

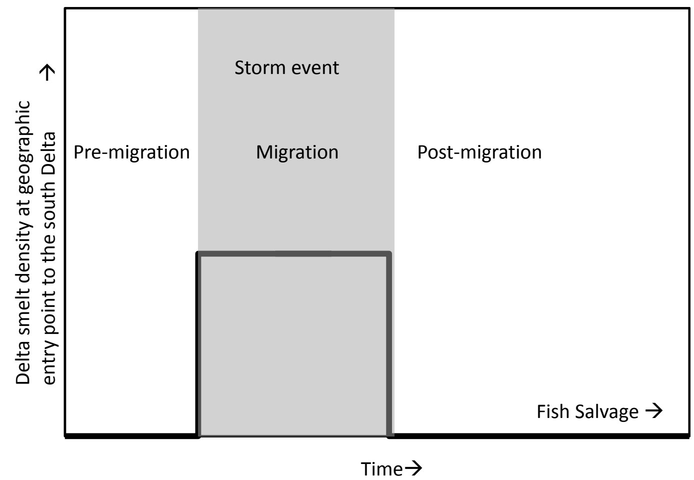

Figure 1. Conceptual model behind the 2014 Jersey Point "early warning" sampling. A storm event initiates a migration of Delta smelt towards the south Delta over a period of time (in grey). Though not explicitly shown, we also considered it possible that multiple storms could result in multiple salvage events.

Methods

Data collection - We used Kodiak Trawling at Jersey Point (SKT station 809) to test our conceptual model. Jersey Point was chosen because Delta Smelt generally must pass by this location in order to reach the south Delta, with the exception of those that first move up the Sacramento River and then pass through Threemile Slough.

The basics of Kodiak trawling have been previously described by Brandes and McLain (2001) and Souza (2002). Briefly, a large net is towed just below the water surface by two boats; the net samples to a depth of about 1.8 m. Volume of water sampled during each tow was estimated using a flow meter deployed alongside one of the boats. When a tow was finished the net mouth was closed by bringing the two boats together and clipping both net wings together on one boat. The second boat then circled around to retrieve fish retained in the cod-end of the net. The cod-end was retrieved using a boat hook and the contents (fish, detritus, plant material) were placed into a live well. All fish were identified to species and measured to the nearest mm fork length, and sexual maturity status was noted by gently pressing on fish to record if they had no gamete expression, eggs, or milt.

Typically 15 tows • day^{-1} were conducted from February 6th to April 10th at near daily sampling intervals (Table 1). The tows were distributed across three lanes corresponding to the north side of the channel (the official location of SKTS station 809; 3 m mean depth), mid-channel (14.5 m mean depth), and south side of the channel (10 m mean depth). A total of 737 tows were done on 51 separate days, with 426 tows in the north (N) lane, 158 tows in the middle (M) lane, and 153 tows in the south (S) lane. This three-lane sampling approach mirrors the trawling conducted by the Service at Chipps Island except that a midwater trawl net towed at the surface by a single boat is used at Chipps Island (Brandes and McLain 2001). Sampling effort was focused on N (median 9 tows • day^{-1}), while the M and S lanes were typically sampled 3-4 tows • day^{-1} (median 3 tows • day^{-1} each). One tow lasted 8 minutes, 732 tows lasted 10 minutes, 3 tows lasted 20 minutes, and the duration of one tow was not recorded. Despite the general consistency in tow duration the volume of water sampled varied substantially from tow to tow (lower quartile=3635m^3; median=4123m^3; upper quartile=4640m^3) due to tidal velocity and location in the channel. Efforts were made to sample on the daylight flood tide as adult Delta Smelt densities in the upper and middle portions of a cross section of the channel are thought to increase during flood tides due to within channel positioning behavior by Delta Smelt (Feyrer et al. 2013), but actual tide state during sampling varied.

Covariate data thought to be important for explaining Delta Smelt abundance and triggering migration were collected both *in situ* and *ex situ* by obtaining data collected from nearby stations. The following six *in situ* data were generally collected immediately prior to each tow: water temperature (°C), water transparency (cm Secchi disk depth), turbidity (NTU), dissolved oxygen concentration (mg/L), specific conductance (μS • cm^{-1}, a proxy for salinity), and water depth (m).

Ex situ data assembled from nearby environmental monitoring stations included: water velocity (ft/s) every 15 min, obtained from the U.S. Geological Survey (USGS) Jersey Point water sample station (http://waterdata.usgs.gov/ca/nwis/uv/?site_no=11337190&agency_cd=USGS); and hourly precipitation data (mm) from a California Department of Water Resources weather station located in Concord, CA (approximately 31km from Jersey Point, station 170, http://wwwcimis.water.ca.gov/). Finally, delta outflow (cfs) was provided by Service personnel. These *ex situ* data were matched to the tow data using the nearest point in time of data collection to tow time.

Table 1. Total catch of Delta smelt by date and lane. * No sampling in south lane due to windy conditions. ** No sampling.

Date	North lane	Middle lane	South lane	Date	North lane	Middle lane	South lane
Feb 6	24	0	2	Mar 11	7	0	*
Feb 10	4	0	0	Mar 12	2	0	0
Feb 11	1	0	0	Mar 13	1	2	0
Feb 12	0	1	0	Mar 14	2	0	0
Feb 13	0	0	1	Mar 15	0	0	0
Feb 14	7	0	0	Mar 16	1	1	0
Feb 15	5	1	0	Mar 17	0	1	0
Feb 16	3	0	0	Mar 18	1	0	0
Feb 17	2	0	1	Mar 25	0	0	**
Feb 18	5	0	0	Mar 26	8	0	0
Feb 19	4	0	0	Mar 27	1	0	0
Feb 20	0	1	0	Mar 28	0	0	0
Feb 21	3	0	3	Mar 29	1	0	0
Feb 25	2	0	0	Mar 30	5	2	0
Feb 27	16	0	0	Mar 31	8	9	0
Feb 28	2	0	1	Apr 1	71	**	**
Mar 1	5	0	1	Apr 2	2	0	0
Mar 2	3	0	0	Apr 3	7	2	2
Mar 3	9	2	1	Apr 4	5	8	2
Mar 4	2	0	0	Apr 5	9	0	3
Mar 5	4	5	1	Apr 6	1	0	0
Mar 6	12	1	2	Apr 7	1	0	0
Mar 7	11	2	0	Apr 8	2	0	0
Mar 8	2	0	2	Apr 9	0	0	0
Mar 9	4	0	0	Apr 10	1	0	0
Mar 10	3	0	0				

Statistical analyses - Three models were built and analyzed to address the three different objectives of the study. The first model was constructed to quantify the influence of local environmental covariates on the tow specific expected catch size, but not how the expected catch size might be changing through time. The second model was constructed to quantify where in time significant increases in daily Delta Smelt catch densities were observed, how long any such density increases persisted, and to qualitatively match predicted increases in densities with storm events. Finally, a third model was built to estimate the probability of detecting Delta Smelt given a particular underlying density and sample volume.

Model 1 - A generalized linear model was built to model tow specific density estimates as a function of local (in time and space) environmental covariates. Let y_t and Vol_t be the catch and sample volume of the tow conducted at time *t*, respectively. The catch density y_t/Vol_t was modeled as:

$$\log_e(y_t/Vol_t) \sim 1 + Lane_t + Turb_t + Cond_t + Cond_t^2 + Vel_t + Precip_t + Outflow_t) \quad \text{(Eqn. 1)}$$

Where ~ denotes "is distributed as" and the abbreviations for each predictor variable and the motivations for including them are as follows:

Lane - A categorical variable for sample lane. The habitat differences between lanes may result in different expected densities across lanes.

Turb - Turbidity (NTU) as measured by the boat prior to each tow. Increases in Delta Smelt density can result from local scale increases in turbidity (Nobriga et al. 2008, Feyrer et al. 2011) as well as larger scale changes, e.g. turbidity changes related to the "first flush" of freshwater into the Delta from the first winter storm (Grimaldo et al. 2009).

Cond - Specific conductance (μS • cm^{-1}, a proxy for salinity), as measured by the boat prior to each tow (Nobriga et al. 2008, Feyrer et al. 2011). Salinity can influence Delta Smelt occurrence, with most fish being caught in water of approximately 0.2 to 2.0 practical salinity units (Bennett 2005).

Vel - Water velocity (ft/s) as measured by the USGS at Jersey Point field station. Water velocity was used as a proxy for tide condition which in turn is thought to influence adult Delta Smelt distributions (Feyrer et al. 2013), with negative values corresponding to flood tides and positive values to ebb tides.

Precip - Precipitation (mm) over the course of the hour in which the tow at time *t* was conducted, as measured by the CDWR station in Concord, CA. During the drought conditions at the time of the survey, increased precipitation would correspond to the first substantial rainstorm of the year, and thus is expected to increase Delta Smelt densities for similar reasons as increased turbidity.

Outflow - Total Delta outflow (cfs). Salvage peaks following a "first flush" of water into the Delta (Grimaldo et al. 2009) suggest a positive relationship between densities at Jersey Point and outflow.

A negative binomial error distribution was chosen for the catch sizes y_t, with the Vol_t fixed as an offset term. A negative binomial error distribution was chosen because of the high frequency of zeroes (579 out of 737 of the tows had $y_t = 0$) and the occasional large catch (maximum of $y_t = 35$ on April 1st by tow number 2 in the N lane). After some graphical exploration of the covariate data and consideration of variance inflation factors, it appeared that the terms in the covariate pairs tow direction (upstream or downstream) and water velocity, and temperature and conductance, were too highly correlated to be simultaneously included in the full model. Model Eqn. 1 was fit using the *glm.nb* function of the MASS package (Venables and Ripley 2002) in the R programming environment (R Development Core Team 2014).

It is important to note that while the model given by Eqn. 1 has a notion of space via the inclusion of the *Lane* term, it lacks a temporal aspect; i.e. the temporal sequence in which the tows at times *t* where carried out is not accounted for. Conceptually, this assumption amounts to a model of catch density whereby any predicted density changes as covariates change cannot be unambiguously associated with migration events. For instance, any significant relationships between densities and environmental covariates could simply be the result of Delta Smelt repositioning themselves in a local area that make them more or less available to the fishing gear. Implicitly however, because increases in either or all of precipitation, outflow, and turbidity related to storm events can be fairly distinct in time, any significant positive correlations with these variables would suggest changes in densities at one of only a few specific moments in time.

Model 2 - A hidden Markov model framework (HMM, Rabiner 1989) was used to model temporal changes of Delta Smelt densities. In contrast to the model in Eqn. 1, HMM's are explicitly time series models, allow estimation of when different "states," e.g. days of migration or non-migration, occur. Because we did not incorporate environmental or spatial covariates into this model, we modeled the daily density estimates (computed as the daily total catch size divided by the daily total water volume sampled) of the N lane only. It was assumed that because the N lane had consistently nonzero densities estimates in contrast to the other lanes (Table 1, Figure 2), analysis of this lane would be the most informative about large-scale (i.e. migration events) temporal dynamics of Delta Smelt densities irrespective of the influence of local (in time and space) environmental covariates on tow specific catch densities.

Let $d_t = y_t/v_t$ be the sample density, where $y_t = \sum_i y_{i,t}$ and $y_{i,t}$ is the total catch by tow i on day t, $v_t = \sum_i v_{i,t}$ with $v_{i,t}$ denoting the sample volume of tow i on day t, and the sums are over all tows in the N lane only on day t. Let $\mathbf{D} = \{d_1,\ldots,d_D\}$, and let $\mathbf{X} = \{X_1,\ldots,X_D\}$ be the corresponding vector of latent, unobserved categorical states, each taking a single value in $\mathbf{M} = \{M_1, M_2\}$, where D is the total number of days from the beginning to the end of the study. The joint probability distribution an HMM is given by:

$$P(\mathbf{D},\mathbf{X}) = P(X_0)\prod_{t=1}^{D} P(d_t \mid X_t)\prod_{t=1}^{D} P(X_t \mid X_{t-1})$$
(Eqn. 2)

We assumed the conditional distribution $P(d_t \mid X_t)$ is normal with mean μ_i and standard deviation σ_i, $i = 1, 2$, depending on the value of X_t; that is, the so called "emission distribution" is assumed to be Gaussian. We label μ_1 and μ_2 such that $\mu_1 < \mu_2$ in order that the elements of $\mathbf{M}$ might be conceptualized as corresponding to two different states, with M_1 corresponding to a non-migration event and M_2 corresponding to days with a migration event.

For HMMs, the Viterbi states are defined as the sequence of underlying unobserved states $\mathbf{X}$ resulting in the highest value of Eqn. 2, given a particular set of emission and transition probability parameters (Rabiner 1989). We used the Viterbi states from the fitted model to estimate for each day whether Delta Smelt densities were most likely to be determined by emission parameters from M_1 or M_2. The model was fit using the function *hmm.fit* in the mhsmm package (O'Connell and Højsgaard 2011) in the R programming environment (R Development Core Team 2014). We used Akaike information criteria (AIC, Burnham and Anderson 2002) to compare whether the HMM was an improvement over simply modeling daily catch density as randomly distributed across days as described by either a Gaussian or a negative binomial (with $\log_e$ sample volume set as an offset term) distribution.

Model 3 - We used data from the N lane to build a model to predict the probability of catching at least one fish for a given sample volume effort and underlying Delta Smelt density. To do this, daily densities d_t (defined as in Model 2) were used as predictor variables in the logistic model:

$$\log_{it}(I_{i,t}) \sim 1+\log_e(v_{i,t}) + d_t \quad \text{(Eqn. 3)}$$

where $I_{i,t}$ is an indicator variable denoting whether at least one fish was caught on tow i of day t, the sample volume set as an offset on the linear predictor scale, and a binomial distribution of the $I_{i,t}$ was assumed. This model was fit using the *glm* function, and predictions obtained from the predict function, in the R programming environment (R Development Core Team 2014).

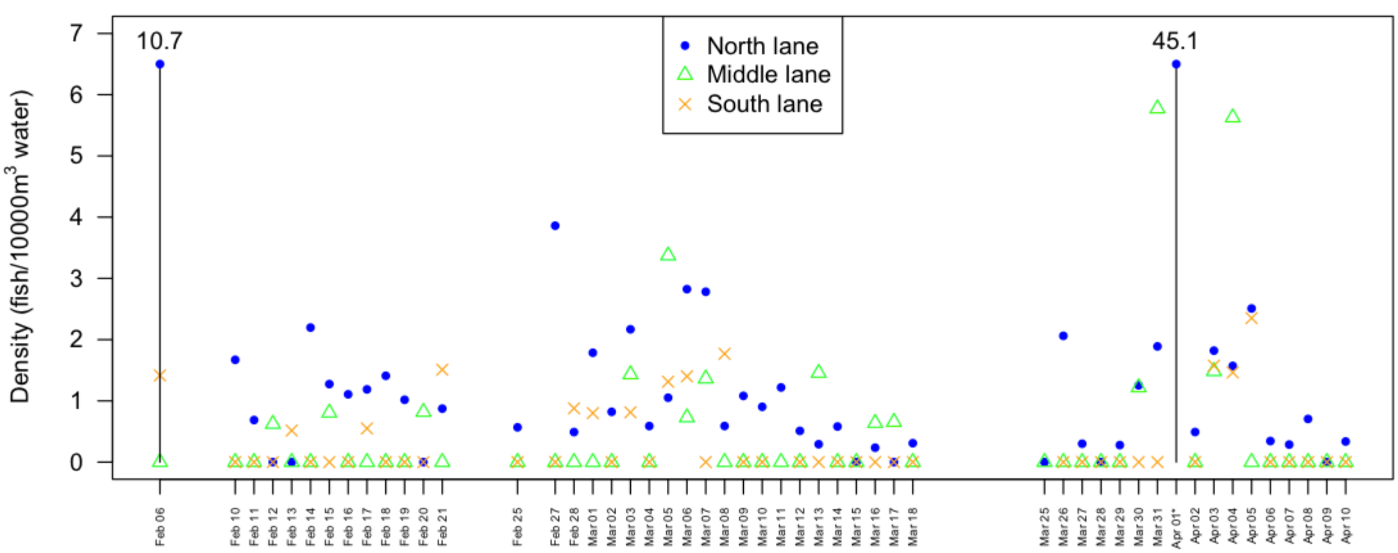

Figure 2. Density by date and lane at Jersey Point. Fish densities for each lane are calculated as the sum of the catches divided by the sum of the sample volumes per day for each lane separately. *The high densities estimated on Feb 6th and April 1st (see Table 1) in the north lane are not placed on the y-axis scale for clarity. Text above these points shows the estimated density on these days.

Results

A total of 329 fish were caught over 51 separate days of sampling (Table 1). Densities (Figure 2) were visually higher on three separate occasions: on approximately Feb 6th, from Feb 27th through the first week of March, and March 31st through April 5th. Changes in large-scale environmental conditions were also recorded (Figure 3), whose increases visually matched the increases in density observed in Figure 2.

The full model for the tow specific data (Model 1) was significantly different from a null model including only the offset term (likelihood ratio test statistic 168.59, df = 7, P-value < 0.01). Two different goodness-of-fit measures (proportion deviance explained = 0.27, McFadden's psedu-R^2 = 0.14) suggested that most variation in the data remained unexplained, and the fitted model under predicted the total number of tows with zero catch totals (observed=579, predicted=565) while failing to predict catch sizes above 7 (5 tows had a catch > 7, with a max of 35). Of the environmental covariate terms considered only water velocity and the south lane sample location (in comparison to the middle lane) were *not* significant at the 0.05 level (Table 2). Notably, fish densities (fish/10000 m^3 water sampled) were substantially higher in the N lane compared with the M and S lanes (Table 1 and Figure 2).

Maximum likelihood estimates of the emission parameters in the HMM for the N lane densities were $\hat{\mu}_1$ = 0.90, $\hat{\sigma}_1$ = 5.13e-5, $\hat{\mu}_1$ = 0.90, $\hat{\sigma}_2$ = 4.76e-2. Of the 51 total days of sampling, the Viterbi state estimates resulted in 3 days with a latent state of M_2 (Figure 4): Feb 6th, Feb 27th, and April 1st. The days with latent state assigned to M_2 match well with days observed to have higher densities (Figure 2 and Figure 4). AIC indicated the HMM was substantially more supported than a model describing the total daily density as coming from either a Gaussian or a negative binomial (with $\log_e$ sample volume set as an offset term) distribution (HMM AIC=-995.28; Gaussian distribution model AIC=-603.08; negative binomial AIC=293.83).

Regarding the model on the probability of catching at least one fish in the N lane (Eqn. 3), the probability of catching at least one fish declined exponentially as sample volume declined, for a given density of fish (Figure 5). Using the median tow sample (4123 m^3) of all tows conducted in this special survey, the probability of catching at least one fish in a *single* tow at the lower, middle, and upper density quartiles was 0.16, 0.23, and 0.35, respectively. In contrast, with the same tow sample volume but assuming 15 tows (resulting in a total sample volume of 61846 m^3), the probability of catching at least one fish at

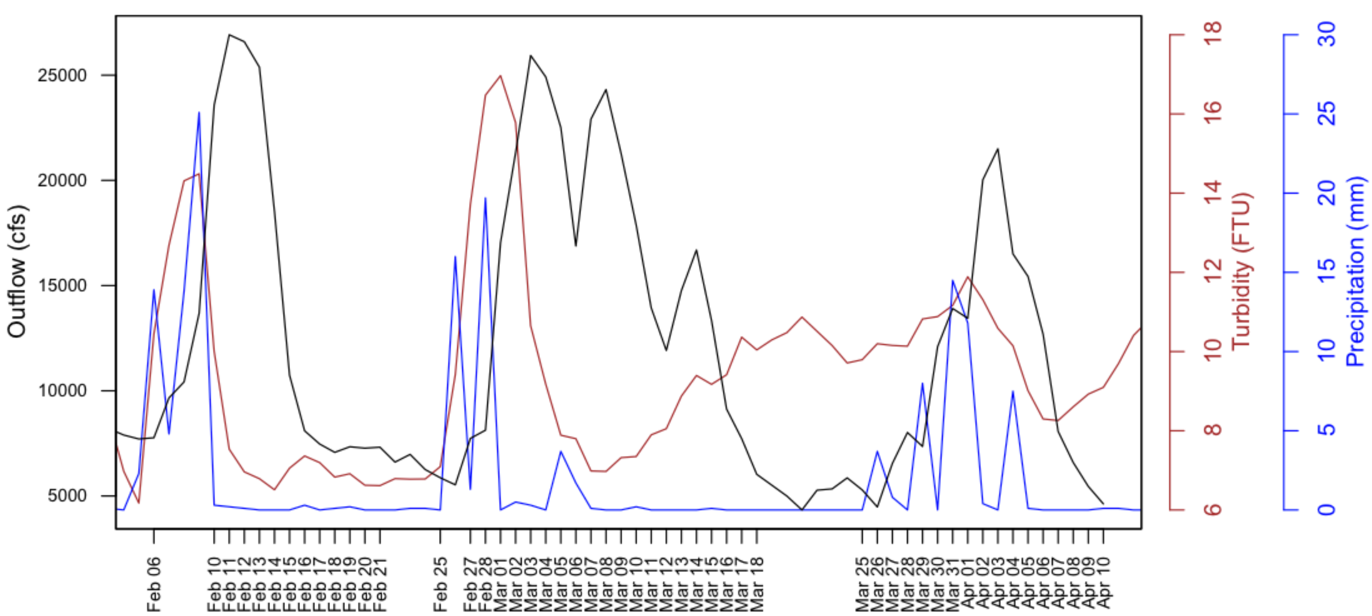

Figure 3. Large scale system changes in response to storm events over the course of the special study sampling. Delta outflow (black), cumulative daily precipitation (blue), and mean daily turbidity (brown) based on USGS 15 min interval turbidity sampling at Jersey Point.

Table 2. Results of the catch size model (Eqn. 1). The dispersion parameter θ was estimated at 0.49 (standard error 0.09) indicating increased aggregation of the data. The intercept term includes the factor levels lane=Middle. *Significant at the 0.05 threshold.

Covariate	*Estimate*	*Std. Error*	*z value*	*P-value*
Intercept	-12.82	0.50	-25.45	<0.01*
Lane (north)	0.69	0.25	2.74	<0.01*
Lane (south)	-0.46	0.35	-1.31	0.19
Turbidity	0.10	0.02	4.35	<0.01*
Conductivity	<0.01	<0.01	3.35	<0.01*
Water Velocity	0.03	0.06	0.50	0.62
Precipitation	0.07	0.02	3.59	<0.01*
Outflow	<0.01	<0.01	2.79	0.01

the lower, middle, and upper density quartiles was 0.74, 0.81, 0.89, respectively.

Discussion

The intensive, near daily sampling at Jersey Point employing nearly 15 tows per day allowed an opportunity to quantify factors influencing catch size at fine spatial and temporal scales. The analyses conducted here revealed a number of covariates associated with catch densities and detected several plausible Delta Smelt migration events. We note that in contrast to a recent intensive survey conducted in 2010-2011 reported on by Bennett and Burau (2014) which caught only 3 Delta Smelt in total in the vicinity of Jersey Point, much greater numbers of Delta Smelt were consistently caught in this study.

From the tow specific analysis (Model 1), while many of the environmental covariates were significant as expected (e.g. turbidity), two results merit elaborated discussion: the significance of the lane effect, and the lack of significance of water velocity. The significantly higher N lane densities in comparison with the M and S lanes suggest micro-habitat spatial variation in an immediate region around the sample station. At Jersey Point, two features in the channel confound unambiguous explanation of the decreases in catch size across the different lanes. On the one hand, the extreme contrast in the riverbank habitat composition (riprap along the south vs. tule edge along the north) suggests that Delta Smelt prefer the tule edge. On the other hand, the variable depths (generally shallower in the north), whereby a lower proportion of the water column is sampled, could mean that fish may simply be located beneath the gear in the middle and south lanes, especially if Delta Smelt are positioning in the mid-water

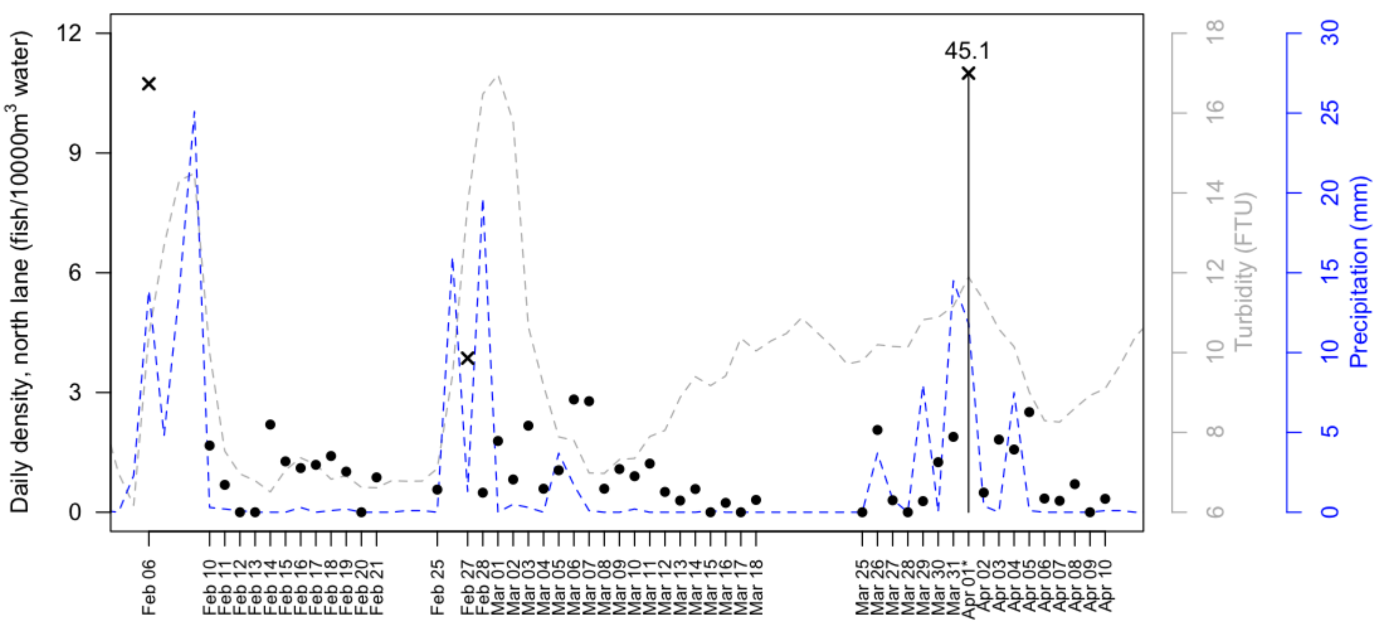

Figure 4. North lane daily densities at Jersey Point. Point characters defined by the migration state estimate from the hidden Markov model (circles for days with low mean densities; crosses for days with high mean densities). Daily mean turbidity (dashed grey line) and total precipitation (dashed blue line) are also shown. *The high density estimated on April 1st (see Table 1) is not placed on the y-axis scale for clarity. Text above this point shows the estimated density on this day.

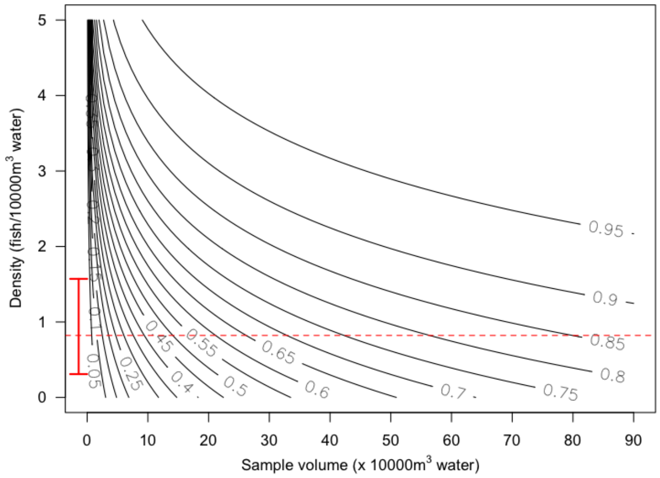

Figure 5. Contour plot showing the probability of catching at least one fish as a function of underlying fish density and sample volume, as predicted by Eqn. 3. The vertical red line shows the interquartile range of observed N lane daily densities, and the horizontal dashed red line shows the median.

or near the channel bottom to avoid the strongest currents or highest light levels. However, the lack of significance in water velocity on the expected catch size was somewhat surprising given the emerging evidence (Feyrer et al. 2013) that Delta Smelt use reverse tides (negative velocities) to facilitate upstream movement.

At the daily time scale (Model 2 analysis), days with particularly high catch densities appeared to follow the three rain events (Figure 4). This positive visual association of where (in time) the mean catch density was substantially higher was generally supported by where the HMM latent states associated with the higher mean density estimate occurred. These results match well with those of Model 1 in that turbidity and hourly precipitation are also (positively) correlated with expected catch size (Table 2). However, not all samples during rain events were associated with significantly higher densities (i.e. the days immediately before and after April 1st), suggesting that the increased densities are not a persistent result of local redistribution of fish in response to a rain event (i.e. fish moving away from the channel edges). Taken together, these findings suggest the observed increases at these three times are associated with some system level change in abundance (i.e., a "migration" event). In addition, the HMM analysis suggests that any detectable changes in density are ephemeral, here lasting only a single day each. The implications for future survey efforts designed to detect mass migration events towards specific regions, e.g., towards the SWP and CVP zone of entrainment, is that daily, or near daily, sampling might be required to detect density changes associated with spawning migration events.

Some of the model limitations and inadequacies must be explicitly discussed. Despite using a negative binomial error distribution, and with an estimated dispersion parameter indicating more heterogeneously distributed count data than with dispersion parameter fixed at one, Model 1 did not explain much of the variation overall (but see Møller and Jennions 2002), and generally showed poor model fitting diagnostics related to under-predicting the frequency of zeroes. The HMM given by Model 2, while being better than simply fitting the data using a single Gaussian or negative binomial distribution, did not incorporate other environmental covariates found to be significant in influencing catch densities, and as such potentially is confounding the influence of local redistribution of Delta Smelt with true changes in Delta Smelt densities. A "gold standard" model would combine both of the model frameworks into a single one to describe the expected tow level densities and the transition probabilities from M_1 to M_2 as functions of local (in space and time) environmental covariates.

Despite the observed and modeled surges in Delta Smelt abundance, some outstanding questions related to migration of Delta Smelt remain. On the one hand, the survey did catch at least one fish on nearly every day of sampling, with only 4 of 51 total sample days not resulting in at least one Delta Smelt being caught (Table 1). One the other hand, the survey did not catch any fish in 579 out of 737 of the tows (78%), a zero catch frequency roughly equal to that of the SKTS. These results are predicted by the findings of the analysis of Eqn. 3 (Figure 5); in any given tow, the probability of not catching any fish is fairly high even for moderate densities of Delta Smelt. Taken together, these observations suggest that intensive sampling resulting in much greater sample volumes than those typically achieved by the monthly SKTS is required to reliably detect the presence of Delta Smelt at densities less than or equal to those present in the location of Jersey Point during the special survey. Echoing the finding that increased sampling beyond a single tow per station per day is necessary to reliably detect Delta Smelt presence when densities are low is the observation that the monthly SKTS did not catch any Delta Smelt in the south Delta upstream of Jersey Point during 2014 with the single exception of three fish caught at SKTS station 923 along the North Mokelumne River in February.

The impetus driving the intensive data collection studied here was the need by the Service for an early warning of when Delta Smelt began moving into the south Delta, and thus increasing the risk of high entrainment. The value of this intensive sampling effort as an early warning signal was mixed. On the one hand, several spikes in Delta Smelt density were observed at Jersey Point, spikes not likely to have been detected using the regular SKTS effort. On the other hand, almost no Delta Smelt were caught upstream of Jersey Point, and no adult salvage was recorded in 2014. Whether the lack of any corresponding increase in catch or salvage upstream of Jersey Point is due to the low probability of catching smelt under the regular SKTS effort, the complex relationship between salvage and entrainment, or both, is not possible to ascertain with intensive sampling at a single station. Future special surveys would need to have multiple, spatially separated, sampling locations which survey for Delta Smelt *simultaneously* such as carried out by Bennett and Burau (2014). Such studies can be viewed as a variation of a spatially-explicit Before-After design (Smith 2002). These locations could be designed to detect whether density spikes observed at Jersey Point were followed by density spikes closer to the area where entrainment related mortality is more certain (e.g. upstream of Prisoner's Point). These efforts might be supplemented with a capture-recapture study to check whether fish captured at Jersey Point are caught further upstream. With an eye towards assessing the proportion of the Delta Smelt population that is vulnerable to entrainment because of spawning migration related movement, additional surveys along the Sacramento River (e.g. near Decker Island, but preferably more widespread) would allow density estimates that could be compared with the San Joaquin River-based density estimates to assess what proportion of the 'on the move' population is susceptible to entrainment.

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The Suisun Bay Problem: Food Quality or Food Quantity?

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Introduction

Data collected by the Interagency Ecological Program's (IEP) Environmental Monitoring Program (EMP) have documented remarkable restructuring of biological communities in Suisun Bay over the past four decades. Manifestations of change include: establishment of the invasive clam *Potamocorbula amurensis* as a keystone species that is a potent consumer of phytoplankton (Kimmerer and Thompson 2014) and copepod nauplii (Kimmerer et al. 1994); significant reduction of phytoplankton biomass and primary production (Alpine and Cloern 1992); restructuring of the zooplankton community through replacement of rotifers, cladocerans and calanoid copepods by non-native cyclopoid copepods having lower nutritional value for fish (Winder and Jassby 2011); and population collapses of multiple species of fish including indigenous species at risk of extinction (Sommer et al. 2007). The scientific and policy communities have both contributed major efforts to understand and address the significant environmental declines seen in the Sacramento-San Joaquin Delta. Scientific clarification on the relative roles of the contributing factors could help focus ongoing large-scale planning efforts, and lead to more reasonable expectations of management outcomes.

The consensus of the broad scientific community, including local experts (Baxter et al. 2010, Hanak et al. 2013) and outside experts (Meyer et al. 2009, NRC 2012), is that population declines in the estuary across multiple trophic levels have been caused by multiple human disturbances. When queried about steps toward rehabilitation, strong majorities of local scientists recommended actions to restore more natural processes in the estuary, giving highest priority to restoring flows and habitat (Hanak et al. 2013). An alternative hypothesis has emerged recently that attributes many of these biological changes to another dominant causative factor -- changes in nutrients due to increased inputs from wastewater treatment plants, the largest of which is the Sacramento Regional Wastewater Treatment Plant (SRWTP). The proposed mechanisms are ammonium (NH_4) suppression of the fast growth potential of diatoms (Dugdale et al. 2007), and selection for different species at all trophic levels as NH_4 loads and the nitrogen (N) to phosphorus (P) ratio increase (Glibert 2010, Glibert et al. 2011). At the trophic level of the primary producers, increased NH_4 inputs have been suggested to contribute to a decrease in phytoplankton biomass due to lower production rates (Dugdale et al. 2007), and a shift in the phytoplankton community through a decrease in diatoms (Glibert 2010, Glibert et al. 2011) and increases in green algae and cyanobacteria (Glibert 2010), dinoflagellates and other flagellates (Glibert 2010, Glibert et al. 2011). Therefore, the alternative hypothesis is that a root cause of restructured biological communities and fish population collapses has been increased wastewater inputs, leading to increased NH_4 concentration and N:P ratio (Glibert et al. 2011).

This hypothesis has important management implications and is now being considered in policies to protect, restore and enhance the Delta ecosystem. California's Delta Plan (Delta Stewardship Council 2011) makes specific reference to it: "Dugdale et al. (2007) has determined that ammonium concentrations may be having a significant impact on phytoplankton composition and open-water food webs because of suppression of diatom blooms in the Bay-Delta," and "Ratios of nutrients in Delta waters are thought to be a primary driver in the composition of aquatic food webs in the Bay-Delta (Glibert et al. 2011)." Our goal here is to examine the ecosystem-scale evidence to determine whether or not it is consistent with the nutrient-focused hypothesis. To do this we asked if patterns of change detected in IEP-EMP monitoring data are consistent with four patterns of change that would be expected if the increase of NH_4 loading and corresponding increase in N:P over the past 3 decades are important drivers of ecological change in Suisun Bay:

(1) A pattern of decreasing phytoplankton biomass that tracked the pattern of NH_4 increase – either a steady

trend of decline or a step decrease after NH_4 concentration exceeded the proposed threshold of 4-10 µM (Dugdale et al. 2007),

(2) A pattern of decreasing diatom abundance that tracked the patterns of increasing NH_4 concentration and N:P,

(3) Trends of increasing abundances of green algae, cyanobacteria, dinoflagellates, and other flagellates,

(4) A phytoplankton community having poor food quality as a proposed outcome of elevated N:P (Glibert et al. 2011).

We used IEP-EMP phytoplankton data collected from 1975-2009 to compare measured changes in Suisun Bay against these expected patterns. Similarities between observed and expected patterns of change would provide evidence supporting the proposition that nutrient forms and ratios are important regulators of biological communities; alternatively, differences between observed and expected patterns would provide evidence against this proposition, supporting the broad consensus that ecosystem damage has been caused by multiple human disturbances and cannot be attributed to a single factor.

Data and Analyses

Using IEP-EMP data (http://www.water.ca.gov/iep/products/data.cfm), we focused our analyses on Suisun Bay where the transformation from a high-chlorophyll diatom-dominated state to one of low chlorophyll and dominance by small phytoplankton cells has been attributed to wastewater inputs of NH_4 (Glibert et al. 2011, Dugdale et al. 2013). From water-quality data (e.g., file "WQ1975-2012/Lab Data 1975-1984x.csv") we computed mean annual chlorophyll-*a* and NH_4 concentrations, and N:P as the ratio of dissolved inorganic nitrogen (DIN) to total phosphorus (TP), in samples collected at stations D7 and D8 (Figure 1) over the period 1975-2012. We computed SRWTP loadings of ammonium-N from measured NH_4 concentrations in plant effluent and effluent discharge for the period of record, 1985 through 2013 (Mussen, personal communication, see "Notes"). We used data from the IEP-EMP benthos program to calculate mean annual abundance of *Potamocorbula amurensis* at site D7-C, the only long-term benthos monitoring station in Suisun Bay (Peterson and Vayssieres 2010). We extracted phytoplankton abundance data from IEP-EMP files "CommonNameData2007.xls" and "2008_2010_ Phyto.xlsx." This record includes 1054 samples collected monthly at stations D7 and D8 between 8 January 1975 and 11 December 2009.

Before proceeding, we want to first communicate important information about the reliability of the IEP-EMP data for assessing changes in phytoplankton community composition. A standard practice of microscopic analysis is to count a minimum of 400 phytoplankton cells per sample, which yields estimates of total cell abundance having an accuracy (95% confidence limit) of ± 10% (Karlson et al. 2010). Abundances of individual species would have lower accuracy, depending on number of cells counted of each species. The number of cells (or colonies) counted in Suisun Bay samples collected from 1975-2007 never reached the standard of 400 (Figure 2). Cell counts were exceptionally low between 1988 and 2007 (Figure 2) when a mean of only 5 cells were counted per sample. These analyses yield estimates of cell abundance with extremely large uncertainty -- the span of the confidence interval (± 89%) is nearly double the value of reported cell abundances. Errors in estimated abundances of subsets of the community, such as diatoms or flagellates, are even larger. Therefore, cell abundances have not been measured with sufficient accuracy to provide reliable estimates of phytoplankton community change over time. However, important policy-shaping conclusions have been drawn from this data set (Glibert 2010, Glibert et al. 2011) so we proceed to use it as a test of the expected phytoplankton responses to changing nutrient inputs. Recognizing the data have errors too large to detect trends of change, we use them nonetheless for consistency with past studies and to determine if we reach similar, or different, conclusions. We note that IEP-EMP samples collected after 2007 were analyzed with a different method, and accuracy of population abundances has improved (2007-2009 mean = 368 cells counted/sample; Figure 2).

In order to increase the power of statistical tests, we aggregated the phytoplankton data by averaging cell abundances from all samples collected each year at the two Suisun Bay stations, and then further aggregated the data by binning cell abundances into six phytoplankton groups: diatoms, dinoflagellates, green algae, cyanobacteria, cryptomonads, and other flagellates (e.g., Prasinophytes, Chrysophytes, Haptophytes, Euglenoids). Even this level of aggregation, however, yields population estimates with errors too large for detecting changes. For example, counts of green algae, which have been reported to increase, averaged fewer than 2 cells per sample from

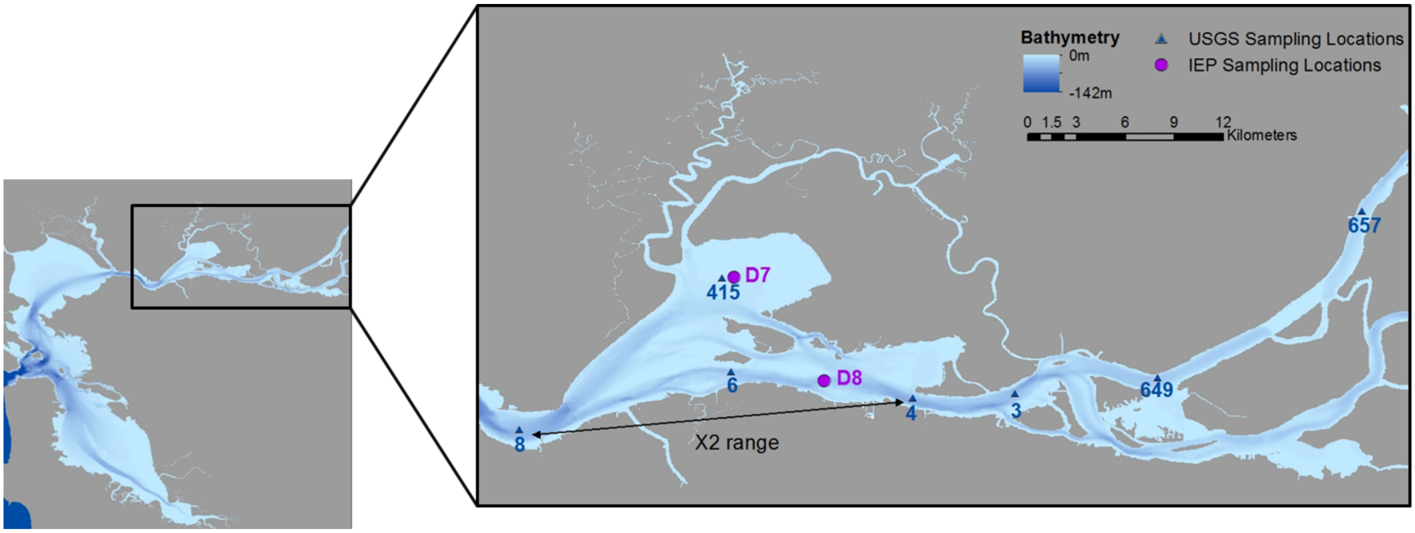

Figure 1. Map showing locations of IEP-EMP stations D7 and D8 and USGS stations in the lower Sacramento River (657, 649) and Suisun Bay (3, 4, 6, 8, 415, location of X2) where phytoplankton were sampled from 1975-2009 and 1992-2014, respectively.

1975-2007. We are preparing a manuscript to explain why trends derived from these kinds of data are highly suspect and do not provide a reliable basis for making policy decisions.

Observed vs. Expected Phytoplankton Patterns

Phytoplankton Decrease Tracked Increasing Ammonium-N Loading?

We used two simple approaches to identify patterns in the IEP-EMP data: the Mann Kendall (MK) test in R package *wq* (Jassby and Cloern 2012) to detect trends over time; and the CUSUM test in R package *changepoint* (Killick et al. 2014) to determine if trends were the result of abrupt step changes. The MK test is a nonparametric method for measuring trends and their significance in series of non-normal variables such as population sizes. The CUSUM test was designed to identify segments of a series that have significantly different means. The MK test confirmed significant increases in NH_4 loading from SRWTP ($p < 0.001$), and NH_4 concentration ($p = 0.001$) and N:P ($p < 0.001$) downstream in Suisun Bay (Figure 2). The smaller rate of NH_4 increase in Suisun Bay (1.5%/year) compared to NH_4 loading upstream (2.6%/year) reflects within-estuary processes of NH_4 consumption, such as nitrification, as wastewater NH_4 is transported downstream.

Next we measured patterns of change in phytoplankton biomass as chlorophyll-*a* concentration (Figure 2). The MK test revealed a highly significant decline ($p = 0.001$) over the period 1975-2012, and the CUSUM test identified a change point in 1987 that divides the series into two eras: 1975-1986 (mean chlorophyll-*a* concentration = 9.9 µg/Liter) and 1988-2012 (mean chlorophyll-*a* concentration = 2.0 µg/Liter). The MK test detected no significant trends of chlorophyll-*a* change in the eras before or after 1987, so the phytoplankton decline in Suisun Bay occurred as a step change rather than a trend over time. If phytoplankton biomass in Suisun Bay has been altered by changes in NH_4 or N:P then we would expect (1) a steady decrease of phytoplankton biomass that mirrored the steady increase of NH_4 loading from SRWTP, and (2) a significant biomass decrease during the period 1988-2012 when NH_4 loading increased from 7.5 to 12.8 tons N/day. However, neither pattern was observed (Figure 2). Instead of a steady decline over time, the 1987 change point signaled an abrupt regime shift when phytoplankton biomass and primary production decreased five-fold (Alpine and Cloern 1992). This regime shift coincided with the population explosion of *Potamocorbula amurensis* within the first year of its appearance in Suisun Bay (Figure 2). However the abrupt decline of phytoplankton biomass was not associated with an equivalent step-change in NH_4 concentration (the CUSUM test revealed no significant change in NH_4 concentration around 1987).

And the chlorophyll-*a* decline occurred before the 1988-2012 period of largest NH_4 loading increase from SRWTP (Figure 2).

These observed patterns of change suggest that the phytoplankton decline in Suisun Bay was caused by an abrupt and permanent increase in grazing mortality rather than to the expected steady decrease in growth rate associated with increased NH_4 loading. This conclusion is supported by measurements demonstrating that *Potamocorbula* filtration is fast enough to control phytoplankton biomass growth (Cole et al. 1992), and disappearance of the large summer diatom bloom that was characteristic of Suisun Bay during the pre-*Potamocorbula* era (Figure 12, Cloern and Jassby 2012).

Diatom Decrease Tracked Increasing NH_4 Loading?

The MK test detected a large and highly significant ($p < 0.001$) diatom decrease in Suisun Bay over the period 1975-2009. However, the pattern of diatom decrease (Figure 3) did not track the increase of NH_4 loading (Figure 2). Instead of a steady loss, the diatom loss was abrupt and it occurred in synchrony with the chlorophyll-*a* decline (Figure 2). The CUSUM test identified a 1987 change point separating a 1975-1986 era of high diatom abundance (mean 1101 cells/mL) and a 1988-2009 era of low diatom abundance (mean 107 cells/mL). One tenet of the alternative hypothesis is that the Suisun Bay diatom loss began after NH_4 inputs from SRWTP started to increase in the early 1980s (Dugdale et al. 2007, Glibert 2010). However, the MK test showed no significant trend of diatom decrease during the 1975-1986 era ($p = 0.11$). This result doesn't discount the possibility of a process that would drive a diatom decline, but any effect of that process was overwhelmed by hydrologic variability during 1975-1986, including the two wettest consecutive years (1982 and 1983) and two driest years (1976 and 1977) on record. The MK test also did not reveal a significant diatom decline during the 1988-2009 era ($p = 0.13$) and this is an important departure from expectations because NH_4 inputs nearly doubled during that period (Figure 2). Therefore, patterns of change in the 35-year IEP-EMP record do not provide evidence that the loss of diatoms from Suisun Bay can be attributed to wastewater inputs of NH_4.

Patterns in the IEP-EMP data do provide strong evidence that the loss of diatoms was a manifestation of the

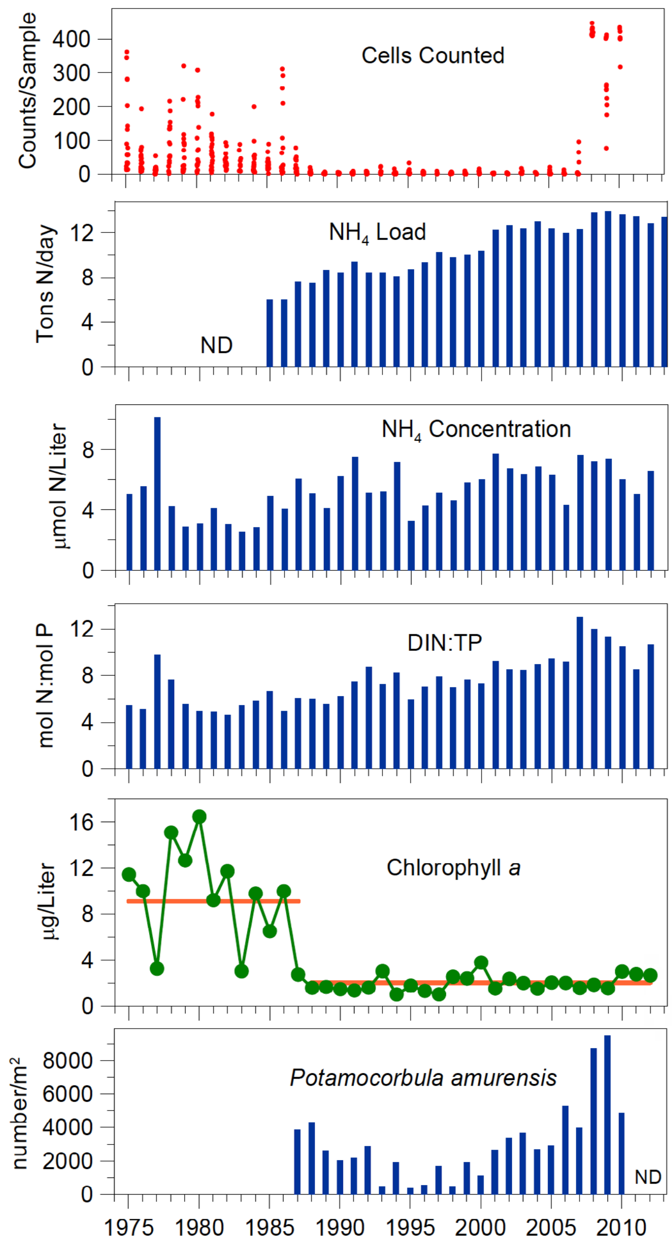

Figure 2. Top panel: number of cells or colonies counted in phytoplankton samples collected at IEP- EMP station D7. Bottom panels show mean annual: NH_4 loading from SR-WTP; NH_4 concentration and N:P ratio in Suisun Bay (means of measurements at stations D7 and D8); chlorophyll-*a* concentration in Suisun Bay (means of measurements at stations D7 and D8); and *Potamocorbula amurensis* abundance (station D7-C). The orange lines in the chlorophyll-*a* panel demarcate a 1987 change point in mean chlorophyll-*a* concentration, synchronous with the establishment of *Potamocorbula* in Suisun Bay. There was no significant trend of chlorophyll-*a* concentration before or after 1987, nor was there a decadal trend in chlorophyll-*a* mirroring the increases in NH_4 concentration and N:P ratio. ND means not determined.

regime shift toward chronic low phytoplankton biomass after *Potamocorbula* became established. The mechanism of this regime shift is confirmed by measurements showing that phytoplankton grazing losses exceed phytoplankton production in Suisun Bay (Kimmerer and Thompson 2014). Early evidence of the power of clam grazing was provided during the 1977 drought when diatom abundance was unusually low (Figure 3). This low-diatom anomaly coincided with salt intrusion that facilitated colonization of Suisun Bay by the marine clam *Mya arenaria* (Nichols 1985). This event previewed the state of low-diatom abundance that has persisted in Suisun Bay since the *Potamocorbula* invasion. Diatoms might be more susceptible to clam grazing than other algae because they sink (Cloern et al. 1983). Sinking transports diatoms to the sediment-water interface where clam filtration occurs, and it could explain why the diatom loss after 1987 (Figure 3) was larger than the chlorophyll-*a* loss (Figure 2). Similar losses of diatoms have occurred in other ecosystems, such as Lake Michigan after invasion by the quagga mussel *Dreissena rostriformis bugensis* (Fahnenstiel et al. 2010).

The collective weight of evidence – synchrony of an abrupt diatom decline with the *Potamocorbula* arrival, absence of the expected trend of a diatom decrease mirroring the trend of increased NH_4 loading, measurements showing that clam grazing is faster than phytoplankton production, and precedents of bivalve invasions leading to diatom declines in other ecosystems – is inconsistent with the proposition that the diatom decline was caused by changing nutrient forms or ratios.

Increasing Abundances of Non-diatoms?

We used the MK test to look for the expected trends of increasing abundances of other algal groups (Figure 3), and found no significant trends of increasing or decreasing abundances of cryptomonads ($p = 0.98$), other flagellates ($p = 0.24$), green algae ($p = 0.25$), dinoflagellates ($p = 0.47$), or cyanobacteria ($p = 0.89$) over the period 1975-2009. Thus, the IEP-EMP data set does not support the proposition that other algae have outcompeted diatoms because their growth is favored by high NH_4 and/or high N:P.

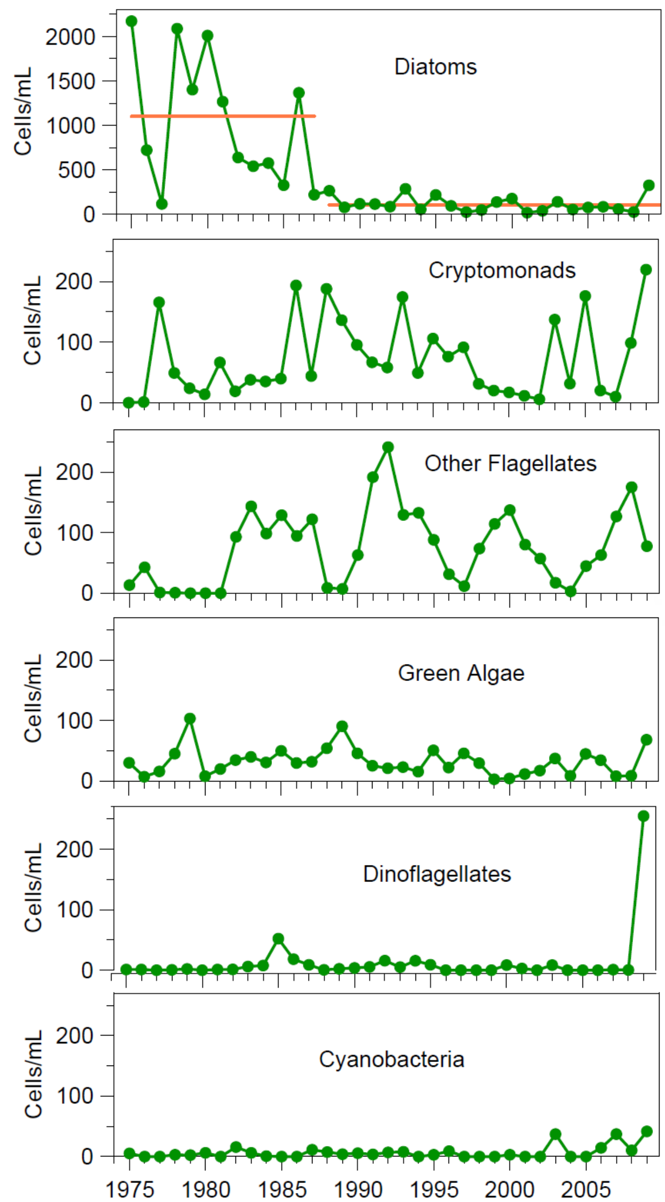

Figure 3. Mean annual abundances of six phytoplankton groups in Suisun Bay (means of measurements at IEP-EMP stations D7 and D8). The orange lines in the top panel demarcate a change point in mean diatom abundance in 1987. There was no trend of diatom abundance before or after 1987, and no trend, upward or downward, for the other phytoplankton groups.

Poor Food Quality?

We tested the expectation of low phytoplankton food quality by computing an index of food quality from measurements of phytoplankton biovolume in 152 samples collected as part of the USGS research program (Cloern and Dufford 2005, Sobczak et al. 2005). Surface samples were collected irregularly during 1992-2014 in Suisun Bay and in the lower Sacramento River below the SRWTP discharge (Figure 1). Phytoplankton biovolume is computed as measured cell volume (μm^3/cell) times abundance (cells/mL) of all phytoplankton species (Cloern and Dufford 2005). The food-quality index is based on laboratory experiments showing that growth efficiency of crustacean zooplankton is highest when they are fed algae enriched in highly unsaturated fatty acids (cryptomonads and diatoms), and lowest when fed algae poor in these essential fatty acids (cyanobacteria; Brett and Müller-Navarra 1997). For each USGS sample we computed:

(1) Food Quality Index = $0.2*P_{cy} + 0.525*P_{gr} + 0.7*P_{di} + 0.95*P_{cr}$

where P_{cy}, P_{gr}, P_{di}, and P_{cr} are the proportions of phytoplankton biovolume in a sample contributed by cyanobacteria, green algae, diatoms, and cryptomonads. The food values of each algal group are from (Park et al. 2003). Similar analyses cannot be applied to the IEP-EMP dataset because phytoplankton biovolume was not consistently measured or reported.

The food quality index ranged from 0.28 to 0.95. It was low (< 0.5) during blooms of cyanobacteria (e.g. *Oscillatoria*, *Aphanizomenon*) or green algae (e.g. *Spirogyra*), but these were rare, occurring in only 5 of 152 samples (Figure 4). The food quality index was high (> 0.7) in 114 of 152 samples where cryptomonads contributed a substantial fraction of biovolume. Phytoplankton biovolume in Suisun Bay and the lower Sacramento River was composed mostly of diatoms (overall mean 62%) and cryptomonads (mean 24%). Cyanobacteria, dinoflagellates and green algae were minor (but episodically important) components. As a result of this community composition, the mean quality of the phytoplankton food resource downstream of SRWTP was high (0.73), and virtually identical to that of a pure-diatom community (0.7). Thus, the USGS data set does not support the proposition that quality of the phytoplankton food resource is impaired by high NH_4 and/or high N:P.

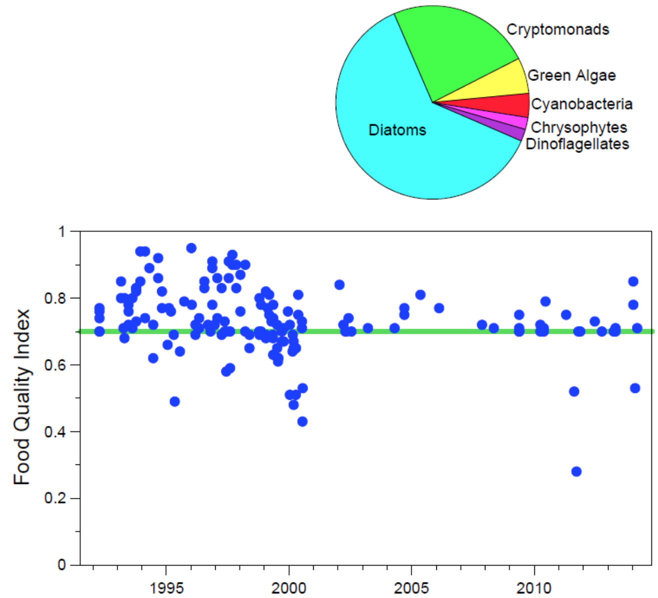

Figure 4. Pie chart shows the mean proportions of phytoplankton biovolume contributed by diatoms (62%), cryptomonads (24%), green algae (6%), cyanobacteria (4%), chrysophytes (2%) and dinoflagellates (2%) in 152 USGS samples collected in Suisun Bay and the lower Sacramento River from 1992-2014 (see map, Figure 1). Bottom graph shows the food quality index of each sample computed from the proportional contributions of diatoms, cryptomonads, green algae, and cyanobacteria to total biovolume. Green horizontal line is the food-quality value for diatoms (0.7).

Conclusion and Management Implications

Independent data sets collected by IEP-EMP and USGS do not provide evidence to support the hypothesis that increased NH_4 or changes in N:P have altered phytoplankton community composition in Suisun Bay or selected for algal species having poor food quality. This conclusion has important management implications. First, it reminds us that phytoplankton populations in Suisun Bay are regulated by many factors, including light limitation of growth by high turbidity (Alpine and Cloern 1988, Jassby 2008), grazing losses to clams and zooplankton (Kimmerer and Thompson 2014), and by variability of freshwater inflow (Cloern et al. 1983, Jassby 2008, Dugdale et al. 2013). Sewage inputs of nutrients may play a role, but the empirical record indicates that its role is overwhelmed by these other factors. Second, this result extends up the food chain because fish populations and their supporting ecosystem functions are also regulated by many factors. Food supply plays a role, but its role in population losses of native fishes is unclear given the effects of other factors such as habitat loss (Whipple et al. 2012) and fragmentation (Sommer et al. 2001), flow modifications (Meyer et al. 2009, Moyle et al. 2010), fish entrainment by water diversions (Rose et al. 2013), changes in salinity and turbidity (Mac Nally et al. 2010, Hasenbein et al. 2013), disruption of food webs by introduced species (Winder and Jassby 2011), and contaminant effects (Brooks et al. 2012).

As we work to unravel the enormous complexity of the San Francisco Bay-Delta ecosystem, it's essential for us to listen to the estuary. The estuary has been telling us for decades that, from an energetics perspective, the Suisun Bay problem (chronic food limitation of consumers) is one of low quantity, not poor quality of the phytoplankton food supply. But more importantly, from a more holistic ecosystem perspective, the estuary has been telling us that the Suisun Bay (and Delta) problem spreads far beyond the single issue of food supply (Baxter et al. 2010). The broad scientific community has reached a strong consensus that the estuary has been damaged over many decades by multiple disturbances, and they have advised that recovery will be difficult and require steps to mitigate each disturbance where mitigation actions are feasible.

The nutrient-focused hypothesis has led some to conclude that recovery of the estuary might be achieved or accelerated by a single action – implementation of advanced wastewater treatment. These conclusions emerge from propositions that: "...a clear management strategy is the regulation of effluent N discharge through nitrification and denitrification. Until such reductions occur, other measures, including regulation of water pumping or manipulations of salinity, as has been the current strategy, will likely show little beneficial effect. Without such action, the recovery of the endangered pelagic fish species is unlikely at best" (Glibert 2010); and "An understanding of the critical role of anthropogenic NH_4 input could provide a powerful tool for management of estuarine productivity, since typically the proportion of the anthropogenic input/loading of NH_4 in these regions can be controlled by changes in water treatment practices and water allocation (dilution)" (Dugdale 2007).

Improvements in wastewater treatment have clear environmental benefits by reducing inputs of nutrients, toxic contaminants, and the oxygen demand of wastewater (e.g. Cloern and Jassby 2012). However, if we accept the proposition that nutrients (forms and ratios) function as a master regulator of the estuary then we face two risks. First, we risk disappointment if the projected outcomes of advanced wastewater treatment, including increased primary production (Dugdale et al. 2007) and return of biological communities to an earlier state (Glibert 2010, Glibert et al. 2011), are not realized. Second, we risk missed opportunities to address the root causes of ecosystem degradation and fish population declines. Our primary purpose here is to remind resource managers of the consistent guidance given by the broad scientific community: "Consideration of the large number of stressors and their effects and interactions leads to the conclusion that efforts to eliminate any one stressor are unlikely to reverse declines in the listed species." (NRC 2012).

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Notes

Dr. Timothy D. Mussen, Sacramento Regional County Sanitation District, provided NH_4 concentrations in plant effluent and effluent discharge from the Sacramento Regional Wastewater Treatment Plant (personal communication, 21 April 2014).

Status and Trends

2013 Benthic Monitoring Status and Trends

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Introduction

The benthic monitoring component of the IEP's Environmental Monitoring Program (EMP) documents changes in the composition, abundance, density, and distribution of the macrobenthic biota within the upper San Francisco Estuary. Benthic species respond to changes in physical factors within the system such as freshwater inflows, salinity, and substrate composition. As a result, benthic community data can provide an indication of physical changes occurring within the estuary. Because operation of the State Water Project can impact the flow characteristics of the estuary and subsequently influence the density and distribution of benthic biota, benthic monitoring is an important component of the EMP. The benthic monitoring data are also used to detect and document the presence of species newly introduced into the upper estuary. These results summarize characteristics of benthic communities found at the EMP's benthic monitoring sites in 2013, and highlight some of the differences seen in the communities between 2012 and 2013.

Methods

Benthic monitoring was conducted monthly at 10 sampling sites distributed throughout several estuarine regions from San Pablo Bay upstream through the Sacramento-San Joaquin Delta (Figure 1). EMP staff collected five bottom grab samples at each station using a Ponar dredge with a sampling area of 0.052 m^2. Four replicate grab samples were used for benthic macrofauna analysis and the fifth sample was used for sediment analysis. Benthic macrofauna samples were analyzed by Hydrozoology,

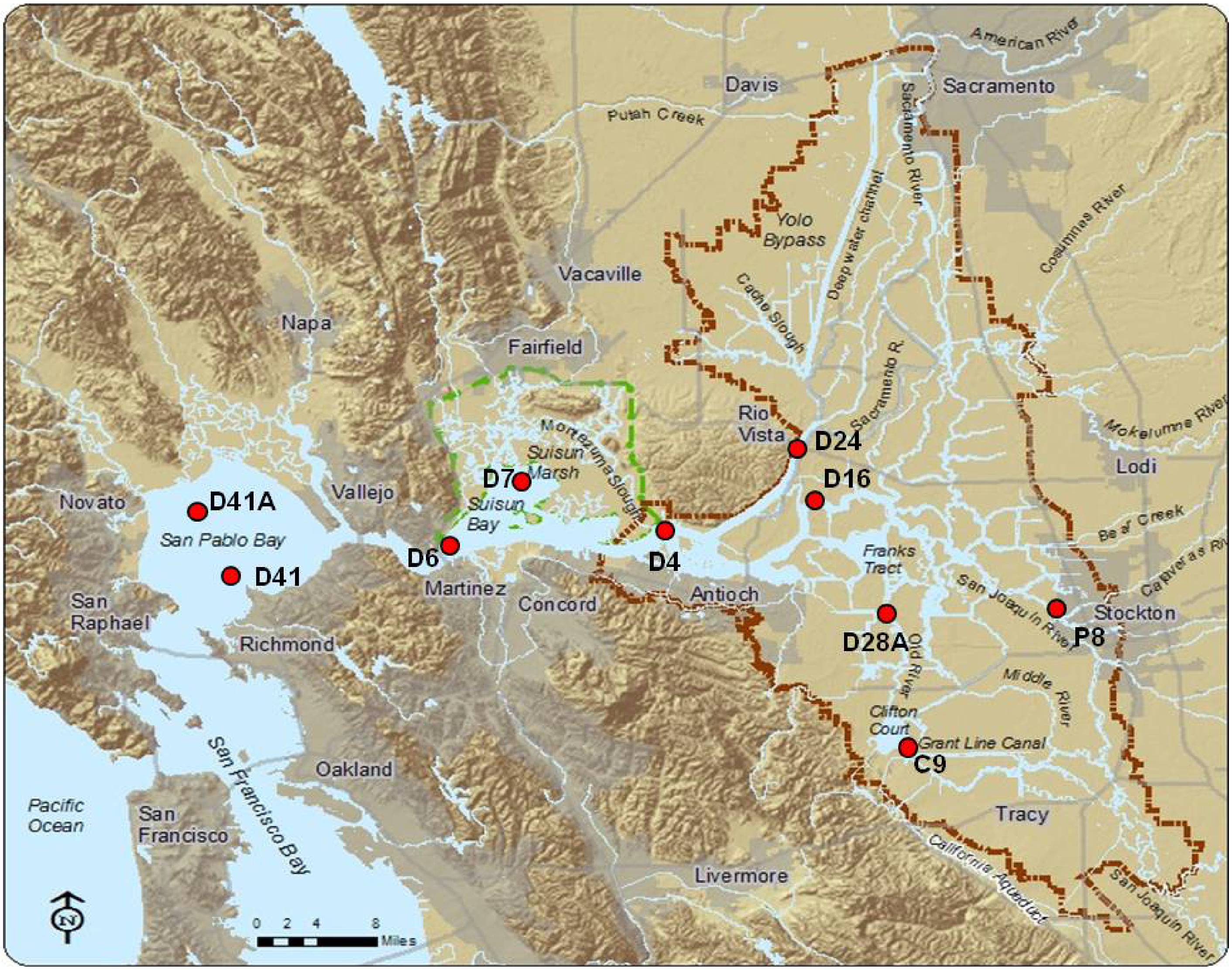

Figure 1. Locations of the Environmental Monitoring Program's (EMP) benthic monitoring stations

a private laboratory under contract with the Department of Water Resources. All organisms were identified to the lowest taxon possible and enumerated. Sediment composition analysis was conducted at the Department of Water Resources' Soils and Concrete Laboratory. Field collection methodology and laboratory analysis of benthic macroinvertebrates and sediment composition are described in detail in the benthic metadata found at http://www.water.ca.gov/bdma/meta/benthic.cfm.

In the following discussion of the results, species densities are reported in two different ways: as annual averages if that species has a steady year-round population, or as peak densities if that species exhibits a strong seasonal pattern with a peak that was at least several times the size of the low. Prior to data analyses, the counts per grab were standardized to individuals/m^2 for each species at each site and sample date. First, individual counts of each species in each of the four replicate grabs was averaged (unless otherwise noted). Since the Ponar grab sampling area is 0.052 m^2, the averaged counts were then divided by 0.052 to find individuals/m^2. The densities for all phyla were then plotted month by month to depict seasonal patterns in benthic communities.

The 2013 water year was designated as dry for the Sacramento Valley, and critical for San Joaquin Valley. The benthic communities at many of the monitoring sites in 2013 were expected to differ from the communities of the sites in wetter years such as 2006 and 2011. Differences were expected both in species composition and in species abundances, particularly at sites in the low salinity zone where the regime switches from a freshwater regime to a more salt-tolerant one.

Results

Two new species were added to the benthic species list in 2013. An unknown species of isopod (Order Isopoda, Family Bopyridae), was collected for the first time in EMP surveys in July 2013. The polychaete worm *Nereis pelagica neonigripes* (Order Phyllodocida, Family Nereididae) was collected for the first time in June 2013. This cosmopolitan species is well known from San Francisco Bay, but this is the first time it has been found in EMP survey sites, perhaps due to a drier water year and a more marine regime in the Delta.

Nine phyla were represented in the benthic fauna collected in 2013: Cnidaria (jellyfish, corals, sea anemones, and hydrozoans), Platyhelminthes (flatworms), Nermertea (ribbon worms), Nematoda (roundworms), Annelida (segmented worms, leeches), Arthropoda (crabs, shrimp, insects, mites, amphipods, isopods), Mollusca (snails, univalve mollusks, bivalves), Phoronida (phoronids), and Chordata (tunicates). Of these phyla, Annelida, Arthropoda, and Mollusca accounted for 98% of all individuals collected in 2013.

Of the 184 benthic species collected in 2013, the ten most abundant represented 86% of all individuals collected throughout the year. These include several amphipods, an ostracod, two Asian clams, and three worms (Table 1). Refer to the Bay-Delta Monitoring and Analysis Section's Benthic BioGuide (http://www.water.ca.gov/bdma/BioGuide/BenthicBioGuide.cfm) or Fields and Messer (1999) for descriptions of the habitat requirements, physical attributes, and feeding methods of most of these 10 abundant species.

North Delta (D24)

D24 is located on the Sacramento River, just south of the Rio Vista Bridge (Figure 1). The substrate at this station in 2013 was consistently made up of sand each month. Mollusca was the most abundant phylum at D24 for much of the year (Figure 2), accounting for 67% of all individual organisms. Nearly all (98%) of the mollusks found at D24 in 2013 were *Corbicula fluminea*, with an average annual density of 1,400 individuals/m^2. *Gam-*

Table 1. Ten most abundant species collected by the benthic monitoring component of the EMP in 2013, as determined by total number of individuals collected.

Species	*Organism Type*	*Native/ introduced status*	*Station(s) at which the species was found[1]*	*Month(s) in which the species was abundant*	*Total number of individuals[2]*
Potamocorbula amurensis	Asian clam	Introduced	D6, D7, D41-A, D4, D41, D24	April through November	47,210
Americorophium spinicorne	Amphipod	Native	D4, D28A, C9, P8, D16, D24, D7, D41A	March through July	34,880
Varichaetadrilus angustipenis	Tubificidae worm	Introduced	D4, C9, D28A, D24, D16	Abundant all year	24,844
Manayunkia speciosa	Sabellidae polychaete worm	Introduced	P8, D28A, C9, D16	Abundant all year	21,771
Ampelisca abdita	Amphipod	Introduced	D41, D41A, D6, D7	June-October	20,684
Gammarus daiberi	Amphipod	Introduced	D28A, D4, C9, D24, P8, D16, D6, D7	March-June, September-November	14,199
Corophium alienense	Amphipod	Introduced	D7, D41A, D6	Abundant all year	11,512
Limnodrilus hoffmeisteri	Tubificidae worm	Unknown; cosmopolitan	C9, D4, P8, D28A, D7, D24, D16	Abundant all year	10,570
Corbicula fluminea	Asian clam	Introduced	D24, D28A, D4, P8, D16, C9	Abundant all year	8,083
Cyprideis sp. A	Ostracod	Unknown	D28-A, C9, P8	February, May, October-December	5,717
Americorophium stimpsoni	Amphipod	Native	C9, D28, P8, D4, D24, D16, D7, D6	May	3,864

[1] For each species, stations are listed in order from highest to lowest total annual abundance.

[2] Total number of individuals was the sum of individuals at all sites at all months in 2013.

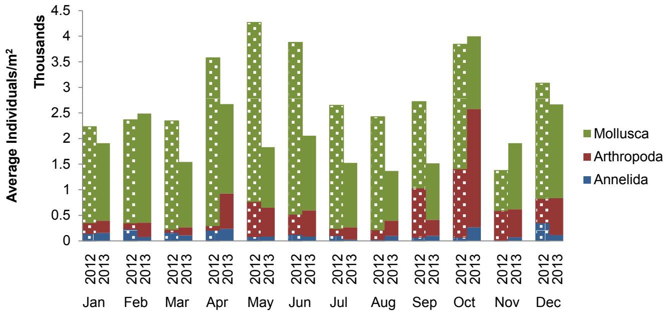

Figure 2. Density of benthic organisms, grouped by phyla, collected at station D24 (Sacramento River at Rio Vista) by month in 2013. Very rare phyla (defined as fewer than 20 individuals total for the year) were omitted from this figure. Columns in solid color are 2013 data, and columns of color dotted with white are 2012 data.

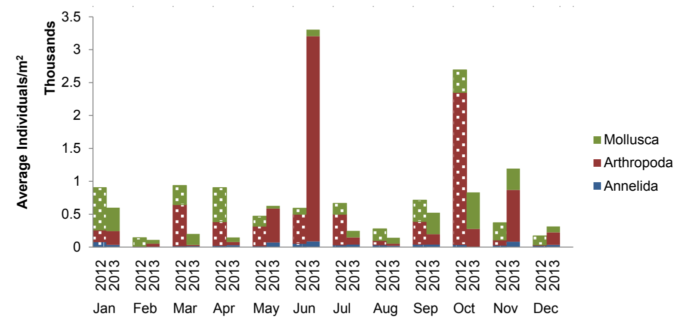

Figure 3. Density of benthic organisms, grouped by phyla, collected at station D16 (San Joaquin River at Twitchell Island) by month in 2013. Very rare phyla (defined as fewer than 20 individuals total for the year) were omitted from this figure. Columns in solid color are 2013 data, and columns of color dotted with white are 2012 data.

marus daiberi made up 77% of all arthropods at D24 in 2013, with a peak of density (up to 1,206 /m^2) in October. *Americorophium spinicorne* also had a high peak density in October of 883 individuals/m^2, over ten times the yearly average density. There were a total of 35 species in six phyla at this station in 2013. The benthic community found at D24 in 2013 was very similar to the community found there in 2012, though *C. fluminea* abundances were slightly lower and *A. spinicorne* abundances were much higher than in 2012.

Central Delta (D16, D28A)

The benthic monitoring program sampled at two stations in the central Delta. D16 is located in the lower San Joaquin River near Twitchell Island (Figure 1). In 2013, the substrate composition of D16 was mostly fines (clay or silt or both), with varying proportions of sand. Arthropoda was the most abundant phylum in May-July and again in November and December, and made up 67% of all organisms collected through the year (Figure 3). The most abundant arthropods at D16 in 2013 were *A. spinicorne* (with a peak in June of 2,603 individuals m^2, ten times the annual average density) and *G. daiberi* (peaking in November at 715 individuals/m^2, five times the annual average). Mollusks made up 27% of all organisms collected and *C. fluminea* was by far the most abundant, with a peak of 556 individuals/m^2 in October. There were a total of 25 species across five phyla at D16 in 2013. D16 was very similar in 2013 species richness and density to the community in 2012.

D28A is located in Old River near Rancho Del Rio (Figure 1). The substrate at this station generally consisted of a high percentage of sand and proportions of fines and organic matter varying greatly through the year, with some months containing large quantities of peat. Arthropods made up 55% of all individual organisms through the year (Figure 4), with peaks in in May of *Cyprideis* sp. A (7,567 individuals/m^2 in that month), *A. spinicorne* (37,724/m^2), and *Americorophium stimpsoni* (5,548/m^2), and a peak in June of *G.daiberi* (6,170 /m^2). Annelids were the most abundant phylum in all months except for May and June. The most abundant annelids were *Varichaetadrilus angustipenis*, with an annual average density of 1,956 individuals/m^2, and *Manayunkia speciosa*, which had a peak of 13,756 /m^2 in February and an annual average of 2,840/m^2. In 2013, there were 66 species in 6 phyla

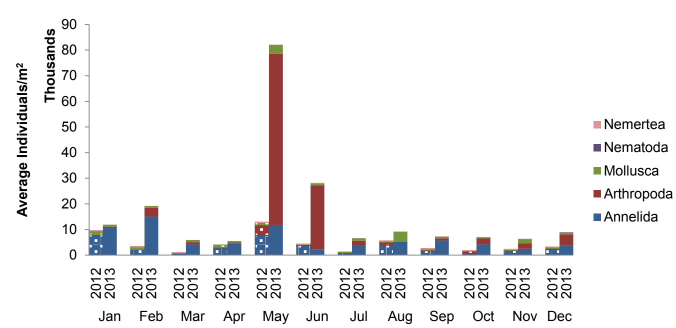

Figure 4. Density of benthic organisms, grouped by phyla, collected at station D28A (Old River) by month in 2013. Very rare phyla (defined as fewer than 20 individuals total for the year) were omitted from this figure. Columns in solid color are 2013 data, and columns of color dotted with white are 2012 data.

at D28A. There were twice as many total annelids and almost fourteen times as many total arthropods at D28A in 2013 as in 2012, representing a substantial change in species densities, although little change in species identities.

South Delta (P8, C9)

The benthic monitoring program sampled at two stations in the southern Delta. P8 is located on the San Joaquin River at Buckley Cove (Figure 1). The substrate was generally made up of a mix of fines (silt or clay or both) with 6-7% organic material. Annelida was the most abundant phyla at this station for all months in 2013, accounting for 74% of all organisms collected (Figure 5). The dominant annelid was *M. speciosa*, which had an annual average density of 4,728 individuals/m^2 and made up 80% of all annelids in 2013. The most abundant arthropods were *A. spinicorne* (peak density in July of 2,741/m^2) and *G. daiberi* (peak density in July of 2,109/ m^2). The most abundant mollusk, *C. fluminea*, was present all year with a peak density of 1,363/m^2 in August, and the most abundant nematode, *Dorylaimus* sp. A, had an annual average density of 105/ m^2. P8 had a total of 55 species in six phyla, with slightly higher densities of annelids, arthropods, and mollusks in 2013 than in 2012. In addition, 2013 had a higher species richness: thirteen rare species of arthropod were collected which were not observed in 2012.

C9 is located at the Clifton Court Forebay intake (Figure 1). The substrate at this station was consistently a fairly even mix of sand and fines (clay or silt), with some low levels of peat and organic matter. Data collection at C9 in January 2013 was prevented by overgrowth of water hyacinth (*Eichhornia crassipes*). Annelida was the dominant phylum for February through December, accounting for 71% of all organisms collected in 2013 (Figure 6). The most abundant annelids were *V. angustipenis* (39% of all annelids, annual average of 3,395 individuals/m^2), *Limnodrilus hoffmeisteri* (31% of all annelids, annual average of 2,689/m^2), and *M. speciosa*, (13% of all annelids, annual average of 1,143/m^2). P8 had a total of 55 species in six phyla, with slightly lower densities of annelids, arthropods, and mollusks in 2013 compared with 2012. However, 2013 had a higher species richness: thirteen rare species of arthropod were collected which were not observed in 2012.

Confluence (D4)

D4 is located near the confluence of the Sacramento and San Joaquin rivers, just above Point Sacramento (Figure 1). In most months fines (clay or silt or both) dominated the substrate at this station, though organic matter (peat) dominated the sample in several months without a clear seasonal trend. Arthropoda was the most abundant phylum from March through June, while Annelida was the most abundant phylum in all other months. *Americorophium spinicorne* was the most abundant arthropod at this station in 2013 (77% of all arthropods collected), with a peak density in May of 34,898 individuals/m^2 (Figure 7). *Varichaetadrilus angustipenis* was the most abundant annelid, with an annual average of 4,432/m^2, constituting 61% of all annelids collected. Among the mollusks, *C. fluminea* and *Potamocorbula amurensis* were both found

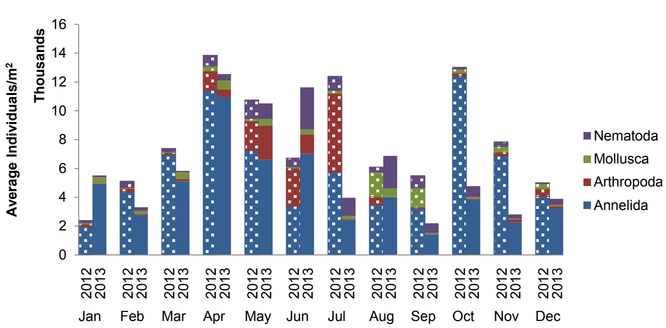

Figure 5. Density of benthic organisms, grouped by phyla, collected at station P8 (San Joaquin River at Buckley Cove) by month in 2013. Very rare phyla (defined as fewer than 20 individuals total for the year) were omitted from this figure. Columns in solid color are 2013 data, and columns of color dotted with white are 2012 data.

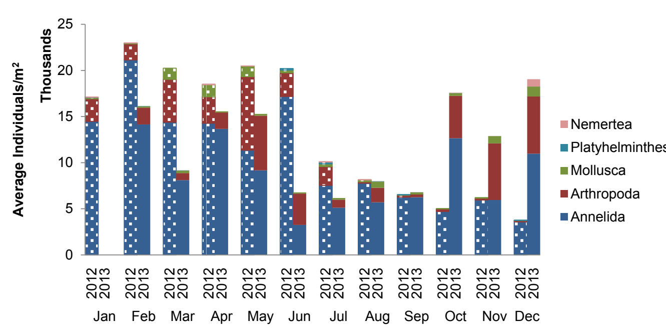

Figure 6. Density of benthic organisms, grouped by phyla, collected at station C9 (Clifton Court) by month in 2013. Very rare phyla (defined as fewer than 20 individuals total for the year) were omitted from this figure. Columns in solid color are 2013 data, and columns of color dotted with white are 2012 data.

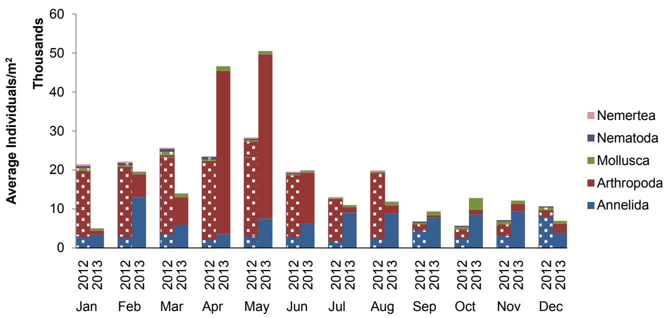

Figure 7. Density of benthic organisms, grouped by phyla, collected at station D4 (Confluence) by month in 2013. Very rare phyla (defined as fewer than 20 individuals total for the year) were omitted from this figure. Columns in solid color are 2013 data, and columns of color dotted with white are 2012 data.

here in 2013 with nearly equal yearly total numbers, but *C. fluminea* density had a fairly steady yearly average of 479 individuals/m^2 while *P. amurensis* had a sharp peak of 2,195 individuals/m^2 in October. There were 39 species in three phyla at D4 in 2013. In 2013, there was higher annelid and molluscan density, but lower arthropod density and diversity, than in 2012.

Suisun Bay (D6 and D7)

The benthic monitoring program sampled at two stations in the Suisun Bay area. D6 is located in Suisun Bay near Martinez (Figure 1). The substrate at D6 was consistently made up of fines (a mix of clay and silt, though generally mostly clay). Mollusca was by far the dominant phylum in all months at this station (Figure 8), accounting for 97% of all organisms collected. With the exception of four individuals from two other species, all mollusks collected at D6 in 2013 were *Potamocorbula amurensis*, which was present through the year with a peak density in October of 23,593 individuals/m^2. Density of *P. amurensis* was approximately 30% higher than in 2012, continuing the upward trend of a 35% increase between 2011 and 2012. However, peak densities of *P. amurensis* in 2013 occurred in October, while in 2012 the peak density was in March. D6 had 29 species in three phyla, and apart from increases in *P. amurensis* was relatively similar to 2012 in density and species richness.

D7 is located in Grizzly Bay, near Suisun Slough (Figure 1). The substrate at D7 was uniformly clay through 2013. Mollusks (primarily *P. amurensis*) were the most abundant phylum for half the year and molluscan densities demonstrate classic recruitment dynamics (Figure 9). *P. amurensis* density jumped from a low in April of 161 individuals/m^2 to a post-settlement peak in May of 20,639 /m^2, and gradually decreased through the rest of the year. The amphipod *Corophium alienense* was the dominant arthropod at D7 in 2013, accounting for 93% of arthropods collected with an annual average of 4,521 individuals/m^2. There were 24 species in three phyla in 2013 at D7. While similar to 2012, D7 had slightly fewer total species and over twice as many *P. amurensis* in 2013, continuing an upward trend at the same rate of increase seen between 2011 to 2012.

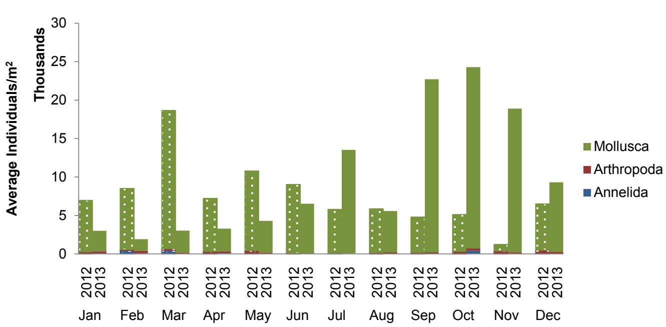

Figure 8. Density of benthic organisms, grouped by phyla, collected at station D6 (Suisun Bay) by month in 2013. Very rare phyla (defined as fewer than 20 individuals total for the year) were omitted from this figure. Columns in solid color are 2013 data, and columns of color dotted with white are 2012 data.

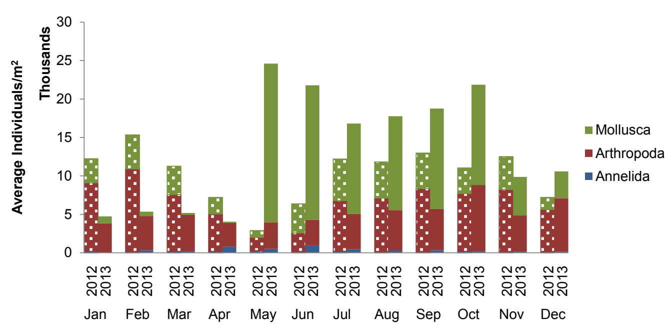

Figure 9. Density of benthic organisms, grouped by phyla, collected at station D7 (Grizzly Bay) by month in 2013. Very rare phyla (defined as fewer than 20 individuals total for the year) were omitted from this figure. Columns in solid color are 2013 data, and columns of color dotted with white are 2012 data.

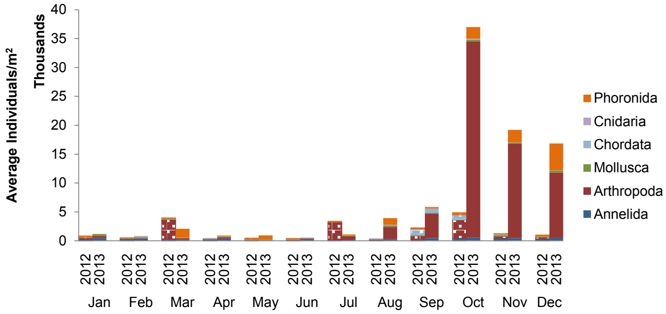

Figure 10. Density of benthic organisms, grouped by phyla, collected at station D41 (San Pablo Bay) by month in 2013. Very rare phyla (defined as fewer than 20 individuals total for the year) were omitted from this figure. Columns in solid color are 2013 data, and columns of color dotted with white are 2012 data.

San Pablo Bay (D41, D41A)

The benthic monitoring program sampled at two stations in San Pablo Bay. D41 is located near Pinole Point (Figure 1) and has a benthic community primarily comprised of marine organisms. The substrate at this station was consistently a mix of fines and sand, with some organics (primarily clamshells). Arthropoda was the most abundant phylum at D41 in 2013, accounting for 77% of organisms collected (Figure 10). The most common arthropod by far was the amphipod *Ampelisca abdita* which accounted for 96% of all arthropods at D41, with a peak abundance in October of 33,720 individuals/m^2. There were 70 species in eight phyla at D41in 2013.The benthic community of D41 in 2013 was similar to 2012 in species richness, but *A. abdita* peak density in 2013 was ten times as high as in 2012.

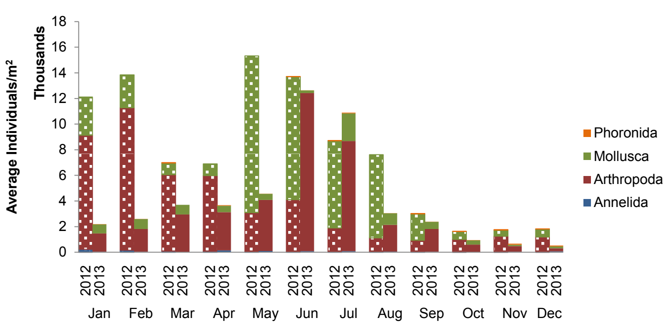

Figure 11. Density of benthic organisms, grouped by phyla, collected at station D41A (San Pablo Bay) by month in 2013. Very rare phyla (d defined as fewer than 20 individuals total for the year) were omitted from this figure. Columns in solid color are 2013 data, and columns of color dotted with white are 2012 data.

D41A is located near the mouth of the Petaluma River (Figure 1). The substrate of this station was made up of fines (primarily clay) in all months. The most abundant phylum in all months was Arthropoda, constituting 82% of all organisms (Figure 11). The arthropods *Ampelisca abdita* (peak density in June of 9,823/m^2) and *Corophium heteroceratum* (peak density in June of 2,308/m^2), as well as the clam *P. amurensis* (peak density in July of 2,104/m^2) all had strong seasonal signals one or two orders of magnitude larger than their lowest densities in 2013. There were 40 species in six phyla at D41A in 2013, with similar diversity to 2012 but a much lower average density of *P. amurensis* in 2013 than in 2012, and with an *A. abdita* peak in June of 2013 compared with January and February in 2012.

References

Fields, W. and C. Messer. 1999. Life on the bottom: Trends in species composition of the IEP-DWR Benthic Monitoring Program. IEP Newsletter 12: 38-41.

2012-2013 Yolo Bypass Fisheries Monitoring Status and Trends Report

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Introduction

Largely supported by IEP, DWR (Department of Water Resources) has operated a fisheries and invertebrate monitoring program in the Yolo Bypass since 1998. The project has provided a wealth of information regarding the significance of seasonal floodplain habitat to native fishes. Basic objectives of the project are to collect baseline data on lower trophic levels (phytoplankton, zooplankton and aquatic insects), juvenile fish and adult fish, hydrology and physical conditions. As the Yolo Bypass has been identified as a high restoration priority by the National Marine Fisheries Service Biological Opinions for Delta Smelt (*Hypomesus transpacificus*), winter and spring-run Chinook Salmon (*Oncorhynchus tshawytscha*), and by the Bay Delta Conservation Plan (BDCP), these baseline data are critical for evaluating success of future restoration projects. In addition, the data have already served to increase our understanding of the current role of the Yolo Bypass in the life history of native fishes, and its ecological function in the San Francisco Estuary. Key findings include: (1) Yolo Bypass is a major factor regulating year class strength of splittail, *Pogonichthys macrolepidotus* (Sommer et al., 1997; Feyrer et al., 2006; Sommer et al., 2007a); (2) Yolo Bypass is a key migration corridor for adult fish of several listed and sport fish (Harrell and Sommer 2003); (3) it is one of the most important regional rearing areas for juvenile Chinook Salmon (Sommer et al., 2001a; 2005); and (4) Yolo Bypass is a source of phytoplankton to the food web of the San Francisco Estuary (Jassby and Cloern 2000; Schemel et al., 2004; Sommer et al., 2004).

This report describes the fisheries sampling effort for the 2013 water year (October 1, 2012 – September 30, 2013), as well as a summary of the fisheries catch by species and gear type. Our sampling mainly occurred in the Toe Drain, a perennial riparian channel on the eastern edge of the Bypass. During drier months, the tidally influenced Toe Drain channel is the primary source of perennial water in the Yolo Bypass, feeding a complex network of canals and ditches. The 2012-13 sampling period yielded high numbers of Delta Smelt, despite the lower observed presence of some adult native fish species (i.e. White Sturgeon (*Acipenser transmontanus*), Chinook Salmon and Sacramento Splittail) in Yolo Bypass.

Methods

Since 1998, juvenile fish have been sampled with an 8-foot rotary screw trap located in the Toe Drain approximately nine miles south of the Lisbon Weir (Figure 1) for up to seven days a week during the months of January – June. In water year 2013, the rotary screw trap was operated consistently five days a week for the entire sampling period without any restrictions from high flows or heavy debris (Figure 2). For the rotary screw trap, it is possible to create rough estimations of the sampling time (total hours based on set and pull times) in order to calculate catch per unit effort (CPUE). At this time, volume of water sampled is unknown.

Upstream-migrating, large adult fish in the Toe Drain are monitored using a 10-foot fyke trap, designed after the Department of Fish and Wildlife's (DFW) fyke traps used for sampling sturgeon and Striped Bass in the Sacramento River. The fyke trap is operated up to seven days a week

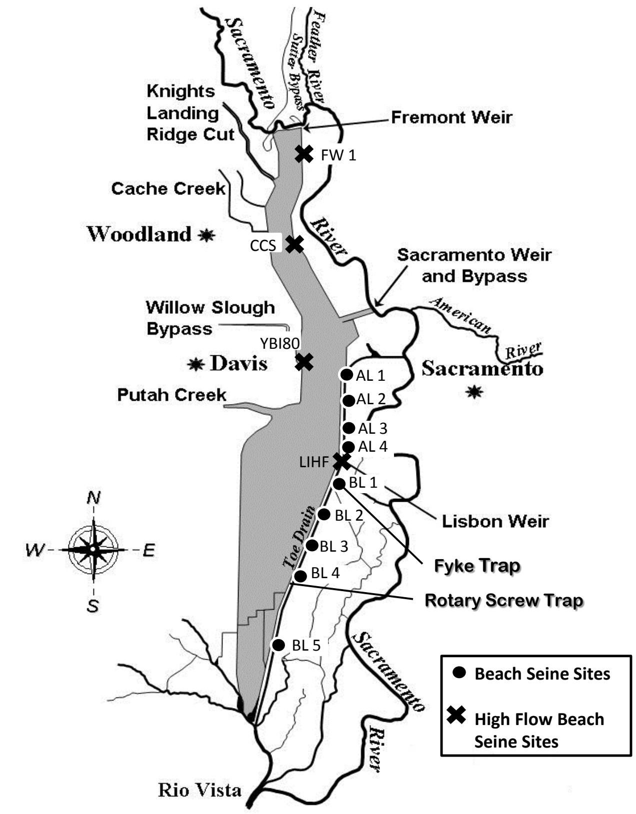

Figure 1. Map of Yolo Bypass.

during the months of October – June (Figure 3). The trap is located ¾ of a mile below Lisbon Weir and 13 miles from the terminus of the Toe Drain (Figure 1).

We have supplemented the collection of small adult and juvenile fish in the Yolo Bypass by conducting biweekly beach seine surveys at various site locations within the Toe Drain and a perennial pond on the

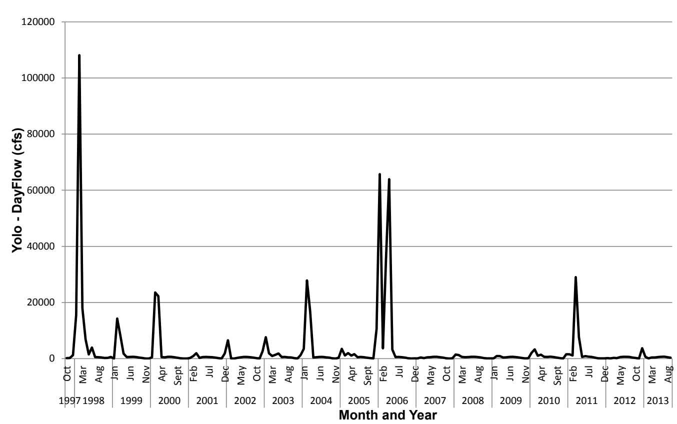

Figure 2. Average monthly Yolo Dayflow water year 1998-2013.

west side of the Bypass (Figure 1 and Figure 3). During inundation events, weekly sampling is conducted (such as in water year 2011) at four distinct site locations only accessible during flood conditions (Figure 1). In the summer of 2010, the non-inundation beach seine survey increased to include seven additional stations, distributed above and below Lisbon Weir, to capture at a higher resolution of the fish assemblage along the axis of the Toe Drain.

To provide data on ambient water quality conditions, field crews concurrently collect data on several water quality parameters including: temperature, electrical conductivity, dissolved oxygen, pH, turbidity, and Secchi depth. Data loggers recording water temperature at 15-minute intervals are deployed at the rotary screw trap (January – June only) and Lisbon Weir (year-round) in the Toe Drain, and for comparison purposes, in the Sacramento River at Sherwood Harbor (Figure 1), also year-round. In addition, chlorophyll-*a* grab samples (to estimate phytoplankton biomass), zooplankton, larval fish, and invertebrate drift samples are collected on a bi-weekly basis (weekly during inundation) at the rotary screw trap and at Sherwood Harbor.

Results and Discussion

The results for water year 2013 were highly influenced by the drier than average spring conditions in the Sacramento Valley. The low precipitation reduced flows and availability of floodplain habitat, altering the water quality conditions and the fish species assemblage. Although there were observed reductions in the catch totals of some natives that are floodplain dependent (i.e. White Sturgeon, Sacramento Splittail and Chinook Salmon), we documented the highest catches for Delta Smelt in the history of the program.

Hydrology

The Sacramento Valley experienced a dry water year type in 2013 (based on Sacramento Valley 40-30-30 water year index) despite a wet December (CDEC, 2014). Average daily flow was 698 cubic feet per second (cfs), based on Dayflow data for flow estimates. The Dayflow flow estimates in the Yolo Bypass are calculated using combined data from the Yolo Bypass flow at Woodland, Fremont Weir spill, and South Putah Creek flow (DWR, 2012). The Fremont Weir did overtop in 2013, and the Yolo Bypass did experience floodplain inundation. The Fremont Weir overtopped from Dec 6th-8th as well as Dec 25th-29th. The maximum stage of the Sacramento River at Freemont Weir was 34.99 ft on Dec 26th. The Toe Drain overbanks at stages greater than 7.16 ft at Lisbon weir. The maximum stage at Lisbon Weir for 2013 was 14.1 ft on December 28th. The flows in the Yolo Bypass in water year 2013 experienced an estimated peak daily flow of 15,698 cfs on December 27th. The minimum daily flow in the Sacramento River was 5,960 cfs on April 24th. The Toe Drain experienced a minimum daily flow of 33 cfs on November 26th (Figure 3).

Water Quality

Water Temperature

The extreme hydrologic variability of the Yolo Bypass, with its susceptibility to floodplain inundation, can cause significant differences in the water temperature when compared to the Sacramento River. When the entire Yolo Bypass is inundated, the wetted area of the Sacramento-San Joaquin Delta is doubled (Sommer et al., 2001a), and this floodplain consists of mainly shallow water habitat (< 2m) with vegetated substrate (Sommer, 2004a). The inundation timing and duration of the Yolo Bypass varies annually, but with longer hydraulic residence times, the increased surface area of the floodplain habitat allows for warmer water temperatures to persist (Sommer et al., 2004b).

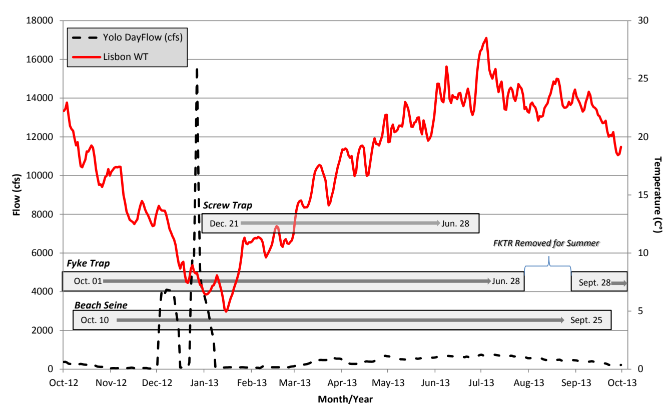

Figure 3. Fishing effort for every gear type summarized against average daily flow (source: Yolo Dayflow) and water temperature.

In water year 2013, water temperature on the Sacramento River at Sherwood Harbor and the Yolo Bypass at Lisbon Weir followed typical seasonal trends, with the highest temperatures occurring in the summer and the lowest temperatures in the late fall and winter (Table 1). However, the Yolo Bypass experienced greater variation in maximum and minimum water temperatures than the adjacent Sacramento River. This higher variation in temperature can be attributed to: (1) the presence of shallow inundated floodplain, (2) lower average velocity, and (3) shallower and narrower channel composition of the Toe Drain relative to the Sacramento River.

Conductivity

Conductivity is used as a surrogate measurement for the seasonal variation of salinity in the water moving through the Yolo Bypass and Sacramento River. The variations in salinity strongly affect the geographic distribution of several listed and non-listed fishes of the San Francisco Estuary (Bulgar et al., 1993; Nobriga et al., 2008). The discrete collection of conductivity data within the Toe Drain of the Yolo Bypass at the Fyke trap site location and the Sacramento River at Sherwood Harbor occurred at each site visit throughout the entire 2013 water year. The lowest conductance values occurred in the Toe Drain during winter months in 2013, which differs greatly from the previous 2012 water year, in which they occurred during the summer months. On average, the Toe Drain had a lower conductance level (less salinity) in the 2012 water year in comparison to the water year of 2013. The lower conductance levels in 2012 were probably largely influenced by a greater amount of water flushing downstream into the Toe Drain from the Fremont Weir overtopping and various side tributaries, aiding in a greater water exchange rate throughout the perennial channel. The greater variation in conductance values observed annually in the Toe Drain as compared to the Sacramento River is likely due to the influence of local tributaries and various agricultural practices, including early summer and fall rice field drainage (Sommer, 2004a).

Turbidity and Secchi Depth

Turbidity was recorded bi-weekly at the fyke trap site in the Toe Drain and in the Sacramento River at Sherwood Harbor year-round in 2013. The annual average water clarity (turbidity, Secchi depth) in the Toe Drain (68.59

Table 1. Statistical summary of Yolo Bypass and Sacramento River at Sherwood Harbor water temperature, conductivity, and secchi depth.

Water Temperature °C								
Month	***Avg.***		***Min.***		***Max.***		***Std. Dev.***	
	Sac	***Yolo***	***Sac***	***Yolo***	***Sac***	***Yolo***	***Sac***	***Yolo***
Oct	17.0	18.6	14.2	15.2	20.1	24.2	1.5	2.1
Nov	13.6	14.3	11.9	12.2	16.1	18.3	1.4	1.8
Dec	10.1	10.1	7.5	6.3	13.3	14.2	1.9	2.4
Jan	7.9	7.7	6.2	4.6	10.2	11.5	1.0	1.9
Feb	10.1	11.0	9.1	9.1	11.7	12.6	0.5	0.7
Mar	13.8	15.6	11.2	12.0	16.9	19.1	1.2	1.6
Apr	17.5	18.8	14.9	15.9	21.2	22.5	1.6	1.4
May	19.9	21.0	17.9	18.6	22.6	24.3	1.0	1.1
Jun	21.9	23.8	19.3	21.3	25.4	29.1	1.0	1.5
Jul	22.0	24.6	20.6	21.1	23.9	31.2	0.8	1.9
Aug	21.6	23.1	20.4	20.3	22.8	27.1	0.5	1.3
Sept	20.3	21.5	17.4	18.0	24.6	25.9	1.3	1.6
Conductivity µS/cm								
Oct	107	655	106	377	107	843	1	114
Nov	126	489	117	403	134	686	12	70
Dec	96	347	74	265	117	432	30	51
Jan	131	473	115	297	171	793	23	148
Feb	129	680	108	523	148	806	17	81
Mar	117	739	115	555	119	852	2	106
Apr	116	568	106	519	127	618	11	31
May	136	558	120	407	151	700	22	81
Jun	121	820	117	560	125	933	6	98
Jul	115	679	106	425	124	933	13	359
Aug	141	379	133	255	149	622	11	210
Sept	20	777	148	618	154	962	4	157
Turbidity NTU (Secchi Depth m.)								
Oct	25.0 (1.63)	60.1 (0.26)	16.8 (1.4)	37.9 (0.18)	33.2 (1.63)	131 (0.38)	11.6 (0.33)	21.7 (0.05)
Nov	31.0 (1.18)	63.9 (0.26)	5.3 (0.87)	33.2 (0.19)	56.7 (1.18)	148 (0.33)	36.4 (0.43)	27.2 (0.04)
Dec	66.4 (0.20)	114.9 (0.12)	58.5 (0.2)	40.6 (0.06)	74.2 (0.2)	693 (0.29)	11.1	173 (0.07)
Jan	33.3 (0.51)	68.3 (0.22)	14.7 (0.34)	34.4 (0.14)	56.0 (0.52)	124 (0.31)	18.3 (0.19)	24.4 (0.05)
Feb	37.8 (0.84)	61.0 (0.23)	7.1 (0.58)	43.0 (0.18)	115.4 (0.84)	92.0 (0.29)	52.0 (0.29)	14.7 (0.03)
Mar	9.3 (1.02)	55.1 (0.23)	6.8 (0.79)	37.4 (0.19)	11.9 (1.02)	71.6 (0.31)	2.6 (0.2)	10.4 (0.03)
Apr	14.7 (0.81)	68.1 (0.21)	7.6 (0.79)	51.8 (0.17)	19.8 (0.81)	101 (0.24)	6.3 (0.02)	13.0 (0.02)
May	10.6 (1.10)	75.1 (0.12)	9.0 (1.1)	20.7 (0.11)	12.2 (1.1)	190 (0.33)	2.3	35.6 (0.05)
Jun	8.3 (1.12)	63.7 (0.19)	6.5 (1.12)	39.3 (0.13)	10.1 (1.12)	101 (0.26)	2.6	17.2 (0.03)
Jul	5.5 (1.36)	97.3 (0.17)	5.4 (1.2)	59.6 (0.11)	5.6 (1.37)	135 (0.22)	0.1 (0.23)	53.3 (0.08)
Aug	7.9 (0.99)	98.3 (0.14)	7.0 (0.88)	50.1 (0.07)	8.7 (0.99)	135 (0.22)	1.2 (0.16)	51.8 (0.08)
Sept	5.6 (1.20)	51.6 (0.23)	5.4 (1.2)	25.3 (0.17)	5.7 (1.2)	63.3 (0.31)	0.2	13.7 (0.05)

NTU, 0.22m) is substantially lower than Sacramento River (22.9 NTU, 0.94 m) (Table 1). Higher turbidity is typical of a seasonally dynamic and abiotically-driven environment such as the Yolo Bypass (Nobriga et al. 2005). The seasonal hydrologic variability of the Yolo Bypass can cause increased turbidity through increased suspended particle concentrations and higher fluctuating temperatures that can increase algal biomass (Sommer et al., 2004a). Lower water clarity has been shown to be beneficial to key fish species in the Delta such as the Delta Smelt (Nobriga, 2008; Sommer and Meija 2013) and this further highlights the importance of Yolo Bypass as a habitat for these native species.

Chlorophyll

The chlorophyll-*a* concentrations on the Sacramento River at Sherwood Harbor reached the annual maximum of 21.68 µg/L on April 3rd, 2013, and minimum of 1.19 µg/L on January 3rd, 2013, with an overall standard deviation of 3.58 µg/L. In comparison, the Toe Drain of the Yolo Bypass at the rotary screw trap site reached a maximum of 31.4 µg/L on September 17th, 2012 and a minimum of 1.72 µg/L on January 3rd, 2013 (Figure 4), with an overall standard deviation of 6.99 µg/L.

In the Toe Drain, chlorophyll-*a* concentrations during water year 2013 exceeded 10 µg/L (threshold for enhanced phytoplankton and cladoceran growth, Mueller-Solger et al., 2002; Schemel et al., 2004) in February, multiple times in March, and in April. In addition, we saw elevated values over 10 µg/L from September – October. These measurements are in contrast to the Sacramento River site, where only one sample was collected on April 3rd, 2013 (21.68 µg/L) that exceeded 10 µg/L. The presence of chlorophyll-*a* values in excess of 10 µg/L has been a rare phenomenon over the past two decades within the Sacramento River and the greater Delta (Winder and Jassby, 2011; A. Mueller, SFEI/ASC 2012 “Pulse of the Delta” presentation). One possible explanation for the high chlorophyll-*a* concentration observed in the Sacramento River in spring 2013 was the extremely low outflow during that period (as observed by the flow monitoring data at Sacramento River at Freeport Bridge, CDEC site: FPT), creating higher residence time and inducing phytoplankton growth (Lucas, 2002; Lucas et al., 2012). Notably, the last observed chlorophyll-*a* value collected at Sacramento River at Sherwood that was in excess of 20 µg/L occurred in April 2008 under similar river hydrologic conditions.

The chlorophyll-*a* trend within the Yolo Bypass for 2013 consisted of peaks in the spring and fall, similar to the fall peaks observed in both 2011 and 2012 (Figure 4). The Yolo Bypass did not experience prolonged floodplain inundation in the winter and spring of 2013, therefore as a result of low residence time of flood waters, the measured chlorophyll-*a* concentrations were at lower levels than those observed in spring 2011 during floodplain drainage (Frantzich et al., 2011).

The elevated levels of chlorophyll-*a* in the late summer and fall of 2013 were measured after increased flows occurred within the Toe Drain due to rice field drainage (Figure 4). In both 2011 and 2012, we observed phytoplankton blooms in the lower Sacramento River that were linked to these Yolo Bypass agricultural flows (Frantzich et.al, 2011; 2012). These blooms were notable, given the generally low productivity of the Delta during the fall and the food web limitations that likely influence abundance of numerous pelagic fish species (Sommer et al., 2007). In 2013, a much more intense and collaborative monitoring effort with DWR, University of California at Davis (UCD), Central Valley Water Resources Control Board (CVWRCB), and the United States Bureau of Reclamation (USBR) closely investigated chlorophyll-*a* concentration before, during, and after the Yolo Bypass fall agricultural drainage period. In addition to chlorophyll-*a*, water samples were also taken for nutrient and phytoplankton species analysis at 11 sites starting in Knights Landing

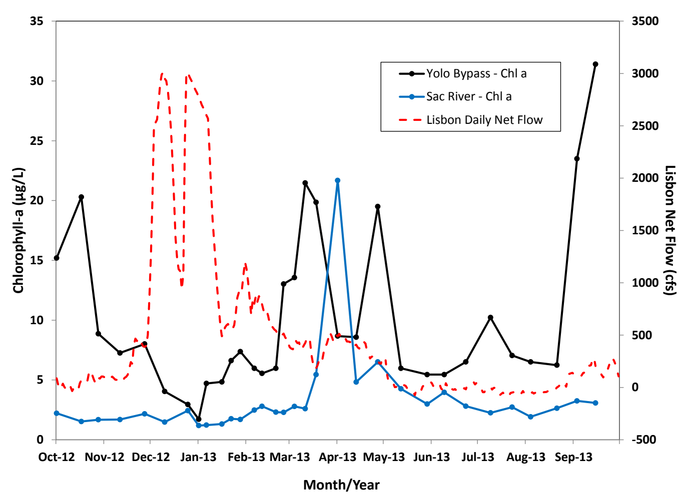

Figure 4. Chlorophyll-*a* concentration October 2012 – September 2013 at Toe Drain of Yolo Bypass and Sacramento River at Sherwood Harbor.

Ridge Cut and ending at the Rio Vista bridge. To provide improved resolution and real-time data on changing water quality conditions, a Yellow Springs Instruments (YSI) sonde was permanently installed in March 2013, with existing flow monitoring equipment in the Toe Drain below Lisbon Weir (CDEC station: LIS). An additional temporary network of two upstream sondes and one downstream sonde at the rotary screw trap were installed to track the downstream transport time of agricultural drainage water and the related changes in water quality conditions. As in previous years of 2011 and 2012, the Yolo Bypass experienced elevated chlorophyll-*a* concentrations in September and October of 2013 as a result of increased fall agricultural flows, but observed flow volume and velocity through the Toe Drain was considerably less. This reduced flow seems to have suppressed the intensity and transport of a phytoplankton bloom downstream into the Sacramento River (Figure 5). These results suggest a flow threshold must be reached to facilitate a downstream bloom. Future work will involve intensified monitoring and sampling efforts to model fluxes of nutrient and phytoplankton throughout the extent of the sampling area, in an effort to determine the relative effects (i.e. sources and sinks) of each region in the development and transport of phytoplankton downstream into the lower Estuary.

Fish

Thirty-nine fish species were sampled during the course of fish sampling activities in water year 2013;

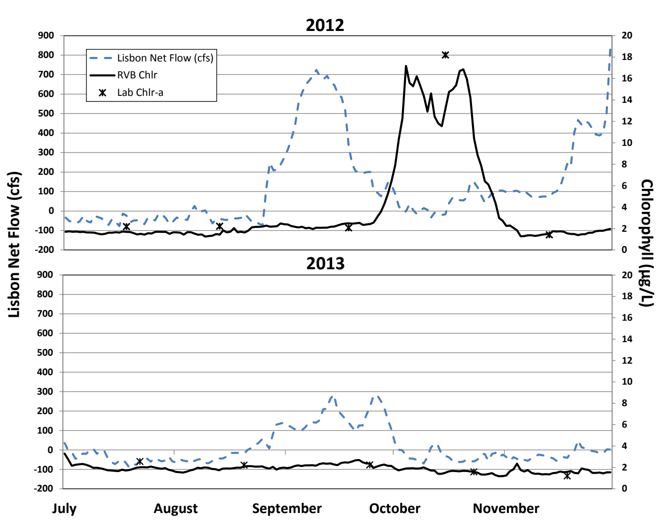

Figure 5. Chlorophyll-*a* grab sample data against mean daily Lisbon flow and RVB chlorophyll data.

14 of which are native to the San Francisco Estuary region (Table 2). The total fish catch from Yolo Bypass was dominated by the non-native Mississippi Silverside (*Menidia audens*), with 17,711 sampled. The high catch of non-native Mississippi Silversides in the Yolo Bypass is not surprising as they have become one of the most abundant fishes in the shallow-water habitats throughout the estuary (Moyle, 2002). In addition, the high catch in the beach seine in 2013 (Table 2) is consistent with high CPUE in favorable shallow perennial channels and ponds of the Yolo Bypass that has been observed historically (Feyrer, 2004; Feyrer, 2006a; Nobriga, 2005).

One of the most notable increases in abundance as compared to the previous sampling seasons was the total number of the Delta Smelt that were collected in the rotary screw trap. Water year 2013 marked the highest number of Delta Smelt caught in the history of the Yolo Bypass Fisheries Monitoring Program.

Delta Smelt

The total catch of Delta Smelt (183) in water year 2013 was the highest on record for the Yolo Bypass Fisheries Monitoring Program (Figure 6, Table 2). The majority of this total was comprised of the adult catch in the rotary screw trap (98 adults/76 juveniles) and only 6 adults/2 juveniles were caught in the beach seine survey. Historically, the timeframe of adult Delta Smelt catch in the Yolo Bypass is from the beginning of January through June. The catch of juvenile Delta Smelt typically begins in May and continues into July, but the presence of both year classes varies annually and is largely affected by hydrologic conditions. In an effort to account for gaps in rotary screw trap operation in other years, we estimated the total hours of rotary screw trap operation for each sampling year and compared the number of adult and juvenile Delta Smelt caught per sampling hour among all years of rotary screw trap operation (Figure 6). This analysis resulted in a combined adult/juvenile catch per hour (CPH) of 0.087 Delta Smelt during the sampling period in 2013. This CPH is as high as 2012 (0.092); the highest Delta Smelt CPH in the history of the Yolo Bypass Monitoring Program. The last two years' catch was incredibly high compare to the average of all years (1997-2013, 0.018).

The previous highest total catch for Delta Smelt occurred in 2012, with a total of 157 fish, predominately adult. Notably, the Sacramento Valley water year classifi-

Table 2. Species catch summarized by gear type for water year 2013. Sorted by descending order of abundance.

Species	*Screw Trap*	*Fyke Trap*	*Beach Seine*	*Total Catch*
Mississippi Silverside	3,478 (16.18%)	0	14,233 (63.80%)	17,711
Threadfin Shad	7,487 (34.82%)	41 (2.15%)	1,952 (8.75%)	9,480
Striped Bass	1,903 (8.85%)	119 (6.24%)	284 (1.27%)	2,306
White Catfish	43 (0.20%)	1,275 (66.82%)	11 (0.05%)	1,329
Western Mosquitofish	131 (0.61%)	0	970 (4.35%)	1,101
Bluegill	9 (0.04%)	5 (0.26%)	986 (4.42%)	1,000
Bigscale Logperch	0	0	845 (3.79%)	845
Black Crappie	33 (0.15%)	122 (6.39%)	200 (0.90%)	355
Delta Smelt	175 (0.81%)	0	8 (0.04%)	183
Splittail	84 (0.39%)	76 (3.98%)	10 (0.04%)	170
Shimofuri Goby	60 (0.28%)	0	82 (0.37%)	142
Chinook Salmon	88 (0.41%)	7 (0.37%)	45 (0.20%)	140
Common Carp	3 (0.01%)	90 (4.72%)	41 (0.18%)	134
Largemouth Bass	3 (0.01%)	4 (0.21%)	117 (0.52%)	124
Channel Catfish	9 (0.04%)	69 (3.62%)	2 (0.01%)	80
Yellowfin Goby	14 (0.07%)	1 (0.05%)	58 (0.26%)	73
Fathead Minnow	6 (0.03%)	0	55 (0.25%)	61
Prickly Sculpin	26 (0.12%)	0	24 (0.11%)	50
Black Bullhead	0	15 (0.79%)	26 (0.12%)	41
Tule Perch	0	0	41 (0.18%)	41
American Shad	5 (0.02%)	33 (1.73%)	2 (0.01%)	40
Redear Sunfish	0	1 (0.05%)	33 (0.15%)	34
Threespine Stickleback	31 (0.14%)	0	1 (0.00%)	32
White Crappie	1 (0.00%)	8 (0.42%)	23 (0.10%)	32
Warmouth	6 (0.03%)	0	20 (0.09%)	26
Golden Shiner	6 (0.03%)	0	19 (0.09%)	25
Sacramento Sucker	0	13 (0.68%)	7 (0.03%)	20
Sacramento Blackfish	0	14 (0.73%)	2 (0.01%)	16
Wakasagi	10 (0.05%)	0	1 (0.00%)	11
Hitch	0	6 (0.31%)	4 (0.02%)	10
Green Sunfish	1 (0.00%)	0	8 (0.04%)	9
Brown Bullhead	0	5 (0.26%)	0	5
Longfin Smelt	4 (0.02%)	0	0	4
AMMOCOETE LAMPREY	3 (0.01%)	0	0	3
Goldfish	0	3 (0.16%)	0	3
Sacramento Pikeminnow	0	0	2 (0.01%)	2
Rainbow / Steelhead Trout	1 (0.00%)	0	0	1
River Lamprey	1 (0.00%)	0	0	1
White Sturgeon	0	1 (0.05%)	0	1
Grand Total	21501	1,908	22,310	45,719

cation types for both 2012 and 2013 were similar (below normal), resulting in low spring outflows (CDEC, 2013). The exact reasons for the higher abundance of Delta Smelt in the Yolo Bypass during drier years have yet to be explored, but possible explanations include: (1) increased upstream distribution, (2) increased numbers entering on flood tides due to the low downstream flow (high negative flow), and (3) favorable habitat conditions. Recent findings have shown that Delta Smelt use the Cache Slough complex heavily throughout both life stages (Sommer and Meija, 2013; Sommer et al., 2011; Merz et al., 2011), and data suggests that there is a population that maintains a year-round residency within Liberty Island, just below the Toe Drain (Sommer and Meija, 2013; Sommer et al., 2011). In recent years, scientists have identified several key Delta Smelt habitat preferences that include: (1) tidal flow (Swanson et al., 1998; Sommer et al., 2011), (2) open water adjacent to habitats with long residence times (e.g. tidal marsh, shoal, low-order channels) (Sommer and Meija, 2013), (3) in or near low-salinity zone (Freyer et al., 2007; 2010 Kimmerer et al., 2009; Sommer and Meija, 2013), (4) high turbidity (> 12 NTU) (Grimaldo et al., 2009), (5) water temperatures < 25 °C (Swanson et al. 2000; Nobriga et al. 2008), and (6) food source primarily made up of calanoid copepods (Sommer and Meija, 2013; Sommer et al., 2011; Nobriga, 2002; Moyle, 2002). It is important to note that several of these habitat preferences are be associated with the perennial Toe Drain of the Yolo Bypass throughout much of the spring, therefore making this location potentially desirable for Delta Smelt at multiple life stages.

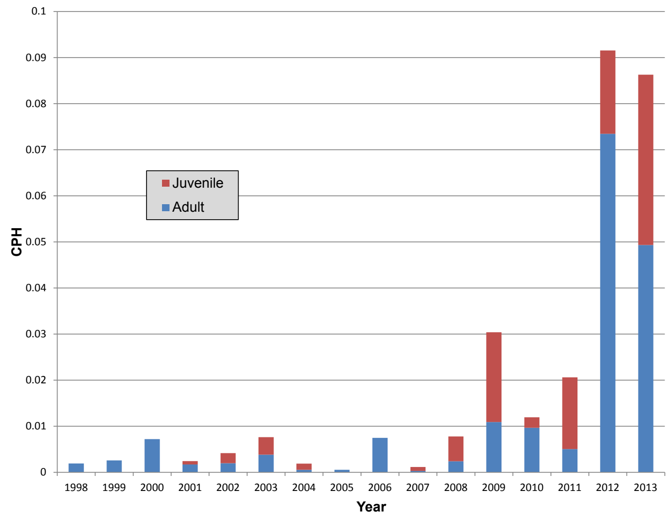

Figure 6. Rotary screw trap adult and juvenile Delta Smelt (CPH, # individuals/hour) by year since the inception of Yolo Bypass Monitoring Program.

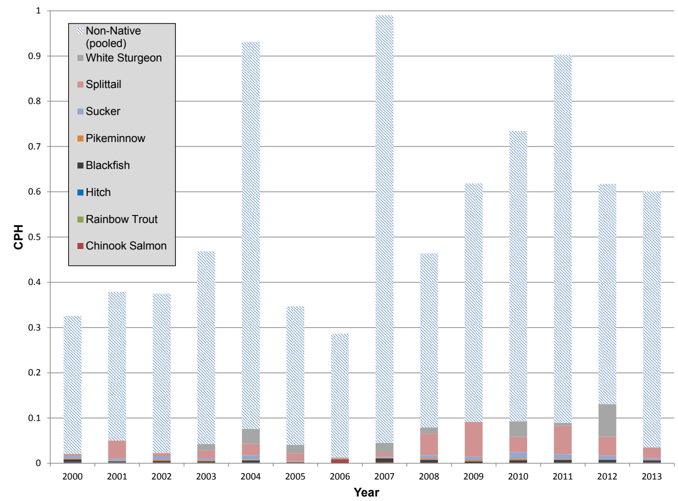

Figure 7. Fyke trap total catch of Native species vs Non-native species-pooled (CPH, # individuals/hour) by year since the inception of Yolo Bypass Monitoring Program.

Reduction in Adult Native Fish

Even though the Yolo Bypass experienced inundation in December, the water year 2013 consisted of a relatively dry winter and spring (Figure 3). The total catch of native adult fish was low in the fyke trap (Figure 7). Since the installation of the fyke trap in 1998, the average catch per hour (CPH) has been 0.5745. This water year, our catch per hour was 0.6012; however, the catch per hour of native species was only 0.0353 versus 0.0596 for the historical average (1998-2013). The total catch of White Sturgeon in the fyke trap for water year 2013 was limited to only one adult (Table 2), even though the highest sturgeon catch on record for the Yolo Bypass Fisheries Monitoring Program was observed in water year 2012 (259 individuals). Prior to water year 2012, the two years with the highest White Sturgeon catch were water years 2004 (168 total) and 2007 (120 total) and each were followed by a years with low catch (2006 & 2009, 1 each). This trend of a high catch followed by a small catch is not likely due to their migration cycle, but rather due to their response to flood pulses (Sommer et al., 2014). Since 2000, the catch of White Sturgeon in the fyke trap has occurred predominately in the months of February, March and April during the upstream spawning migration period (Moyle, 2002; Khohlhorst, 1976; Schafter, 1997). Water year 2013 experienced semi-dry conditions during that period, and this lack of precipitation may have affected upstream migration patterns.

Future Work

Since the spring of 2012, DWR, UC Davis, and USBR have initiated an ERP funded research project involving acoustic telemetry to understand movement patterns of adult salmon and White Sturgeon, as well as juvenile salmon migration patterns and residence times in the Yolo Bypass, genetics to determine run classifications of Chinook Salmon that use the Yolo Bypass, and investigate the possibility of an isotopic signature of Yolo Bypass residence on the otoliths of juvenile salmon. In addition, the project supports the analysis of more than a decade of data on lower trophic organisms in the Yolo Bypass. Also in 2013, DWR expanded its program to further investigate fall phytoplankton production in the Toe Drain of the Yolo Bypass and to determine timing of downstream export.

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State Water Resources Control Board
U.S. Bureau of Reclamation
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